Building materials

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Building materials

Lecture 7

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Cement
continuation

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Cement hydration

- series of irreversible chemical reactions between cement and water
- during hydration the cement sets and hardens, “gluing” the aggregate together in a solid mass

Hydration depends on:

- cement type (chemical composition)
- fineness
- amount of water added
- presence of other admixtures

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Cement hydration

- when water is added - mostly exothermic reactions occur
- evolution of heat (monitored by conduction calorimetry) → **5 stages**:

1. **Pre-induction**
2. **Dormancy** (induction period)
3. **Setting and hardening**
4. **Cooling**
5. **Densification**

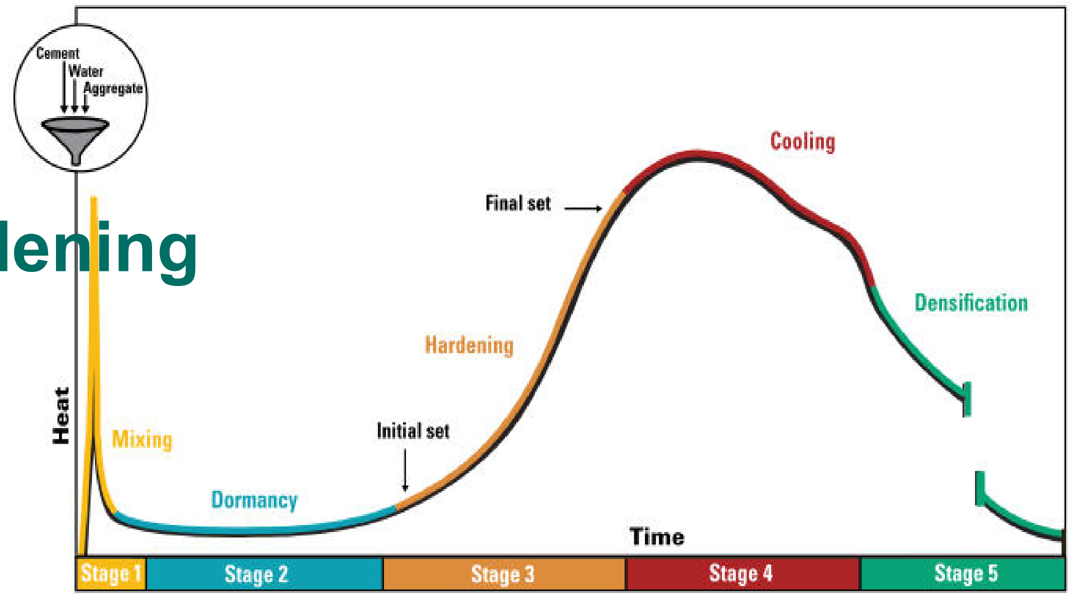
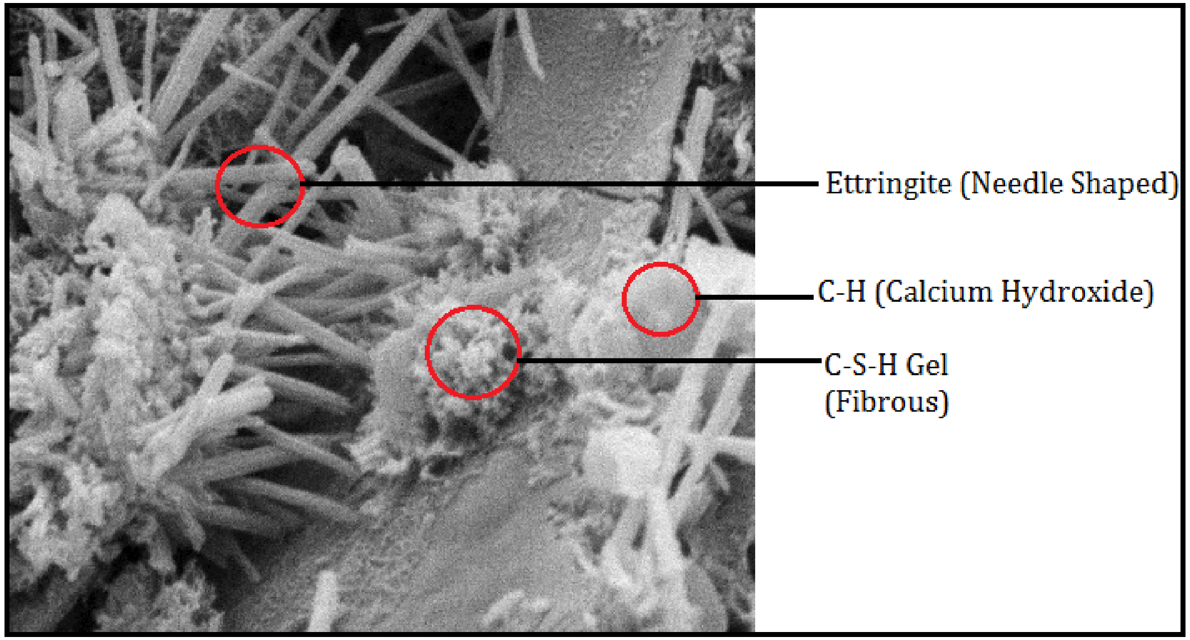


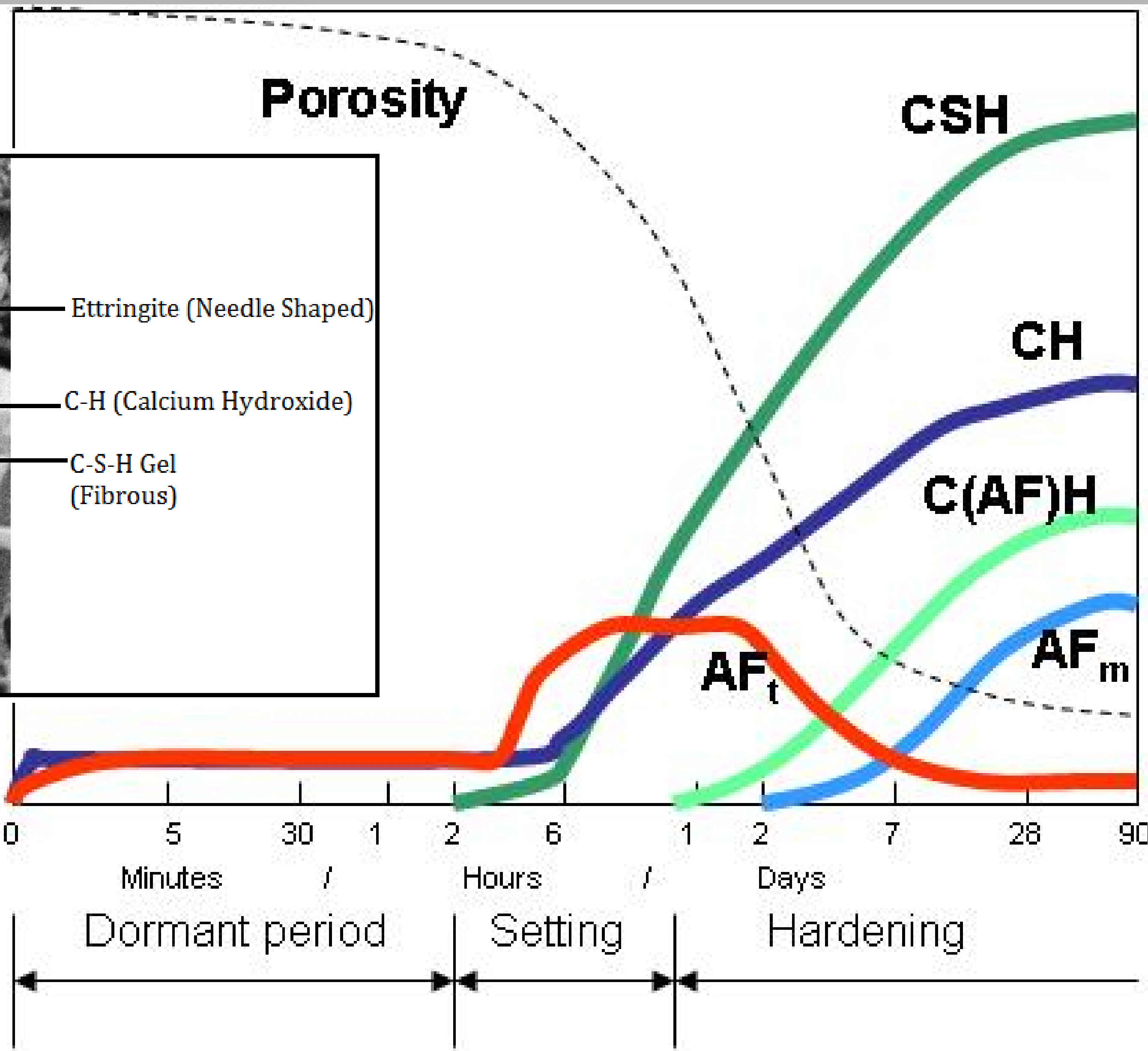
Figure 4-2. General hydration curve delineating the five stages

Products of cement hydration

- **Calcium silicate hydrate (**abbrev. C-S-H)**:**
  - main reaction product
  - main source of concrete strength.
- **Calcium hydroxide** $Ca(OH)_2$ = portlandite (abbrev. CH)
  - formed mainly from alite
- **AFm and AFt phases:**
  - most common AFm - monosulfate ($C_3A.CaSO_4.12H_2O$)
  - most common AFt - ettringite ($C_3A.3CaSO_4.32H_2O$)
- **Monocarbonate:**
  - produced in the presence of fine limestone as some of the limestone reacts with the cement pore fluid ($C_3A.CaCO_3.11H_2O$)

Products of cement hydration





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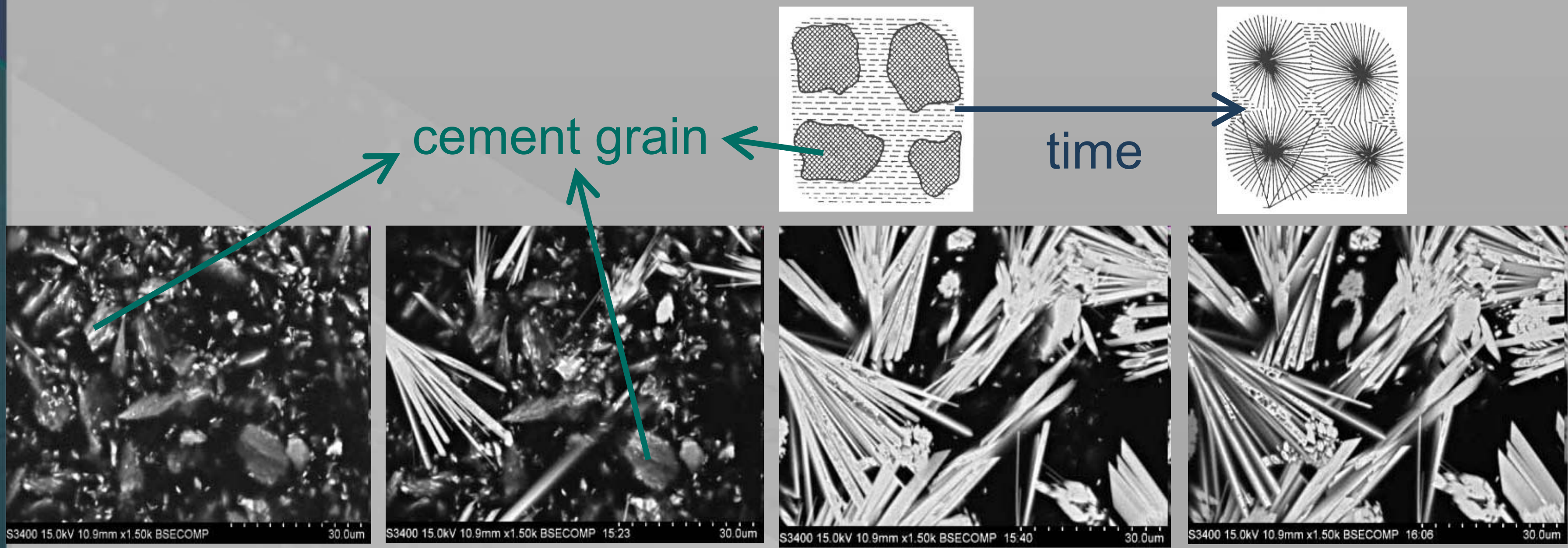
Cement setting and hardening

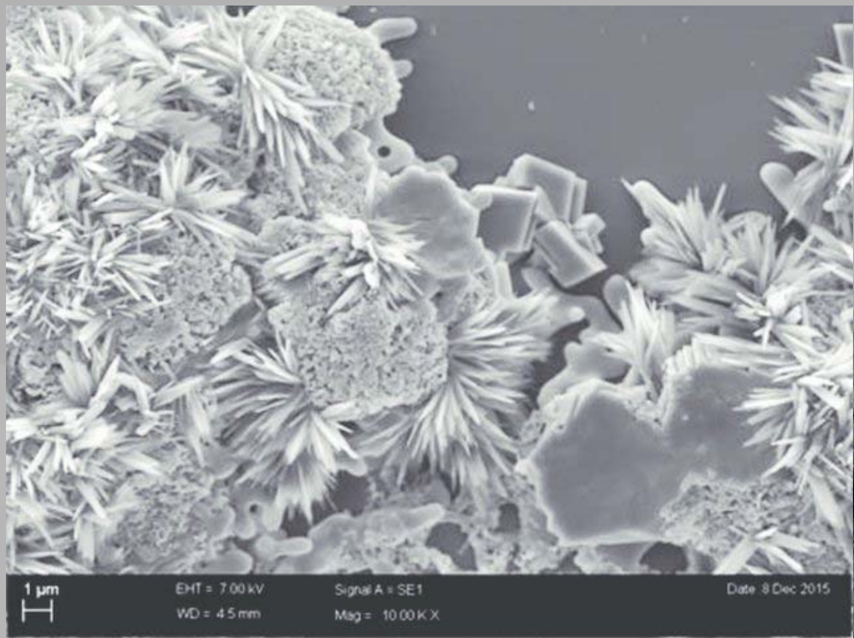
- **Setting**:
  - stiffening of the original plastic mass due to initial gel formation.
- **Hardening**
  - development of strength, due to crystallization
  - crystals form and interlock with each other

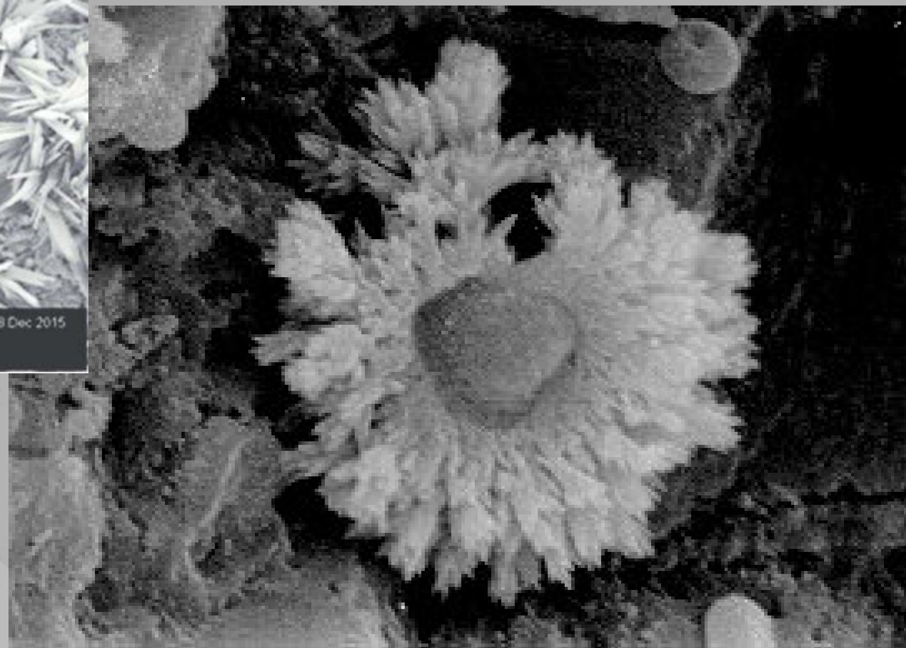


0 min **15 min** **30 min** **55 min**

Cement hydration

- **SEM** (scanning electron microscope) **images of hydrated cement grains**





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Cement types (EU)

EN 197-1: 5 main types - 27 common cements

- **CEM I - Portland cement**
  - min 95% of clinker
- **CEM II - Portland composite cement**
  - up to 35% of siliceous fly ash
- **CEM III - Blastfurnace cement**
  - up to 95% blastfurnace slag
- **CEM IV- Pozzolanic cement**
  - up to 55% of pozzolana
- **CEM V - Composite cement**
  - up to 80% of blastfurnace slag or fly ash and pozzolana

27 Products in the family of Common Cement / Cement Types

EN 197-1

Main Types	Notation of the 27 products (types of common cement)		Composition [proportion by mass[1)]] – Main constituents: Clinker K	Blastfurnace slag S	Silica fume D[2)]	Pozzolana natural P	Pozzolana natural calcined Q	Fly ash siliceous V	Fly ash calcareous W	Burnt shale T	Limestone* L	Limestone* LL	Minor Additional constituents
CEM I	Portland cement	CEM I	95-100	--	--	--	--	--	--	--	--	--	0-5
CEM II	Portland-slag Cement	CEM II/A-S	80-94	6-20	--	--	--	--	--	--	--	--	0-5
		CEM II/B-S	65-79	21-35	--	--	--	--	--	--	--	--	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	--	6-10	--	--	--	--	--	--	--	0-5
	Portland-Pozzolana cement	CEM II/A-P	80-94	--	--	6-20	--	--	--	--	--	--	0-5
		CEM II/B-P	65-79	--	--	21-35	--	--	--	--	--	--	0-5
		CEM II/A-Q	80-94	--	--	--	6-20	--	--	--	--	--	0-5
		CEM II/B-Q	65-79	--	--	--	21-35	--	--	--	--	--	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	--	--	--	--	6-20	--	--	--	--	0-5
		CEM II/B-V	65-79	--	--	--	--	21-35	--	--	--	--	0-5
		CEM II/A-W	80-94	--	--	--	--	--	6-20	--	--	--	0-5
		CEM II/B-W	65-79	--	--	--	--	--	21-35	--	--	--	0-5
	Portland-burnt shale cement	CEM II/A-T	80-94	--	--	--	--	--	--	6-20	--	--	0-5
		CEM II/B-T	65-79	--	--	--	--	--	--	21-35	--	--	0-5
	Portland-limestone cement	CEM II/A-L	80-94	--	--	--	--	--	--	--	6-20	--	0-5
		CEM II/B-L	65-79	--	--	--	--	--	--	--	21-35	--	0-5
		CEM II/A-LL	80-94	--	--	--	--	--	--	--	--	6-20	0-5
		CEM II/B-LL	65-79	--	--	--	--	--	--	--	--	21-35	0-5
	Portland-composite cement[3)]	CEM II/A-M	80-94					← 6-20 →					0-5
		CEM II/B-M	65-79					← 21-35 →					0-5
CEM III	Blastfurnace cement	CEM III/A	35-64	36-65	--	--	--	--	--	--	--	--	0-5
		CEM III/B	20-34	66-80	--	--	--	--	--	--	--	--	0-5
		CEM III/C	5-19	81-95	--	--	--	--	--	--	--	--	0-5
CEM IV	Pozzolanic cement[3)]	CEM IV/A	65-89	--	← 11-35 →					--	--	--	0-5
		CEM IV/B	45-64	--	← 36-55 →					--	--	--	0-5
CEM V	Composite cement[3)]	CEM V/A	40-64	18-30	--	← 18-30 →			--	--	--	--	0-5
		CEM V/B	20-38	31-50	--	← 31-50 →			--	--	--	--	0-5

1) The values in the table refer the sum of the main and minor additional constituents.

2) The proportion of silica fume is limited to 10%.

3) In Portland-composite cements CEM II/A-M and CEM II/B-M, in Pozzolanic cements CEM IV/A and CEM IV/B and in Composite cements CEM V/A and CEM V/B the main constituents besides clinker shall be declared by designation of the cement.

* L: total organic carbon (TOC) shall not exceed 0.5% by mass; LL: TOC shall not exceed 0.20% by mass.

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Cement constituents

- **Portland cement clinker (K)**
  - made by sintering a mixture of raw materials
- **Granulated blastfurnace slag (S)**
  - made by rapid cooling of a slag, as obtained by smelting iron ore in a blastfurnace
  - possesses hydraulic properties when suitably activated

Cement constituents

Pozzolanic materials

– natural substances of siliceous or silico-aluminous composition

– when finely ground and in the presence of water, they react with dissolved calcium hydroxide $Ca(OH)_2$

- **Natural pozzolana** (volcanic origin) **(P)**
- **Natural calcined pozzolana (Q)**

– activated by thermal treatment

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Pozzolanic materials

- contain active silica (SiO_2)
- not cementitious in itself but will, in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form cementitious compounds
- silica must be glassy and amorphous

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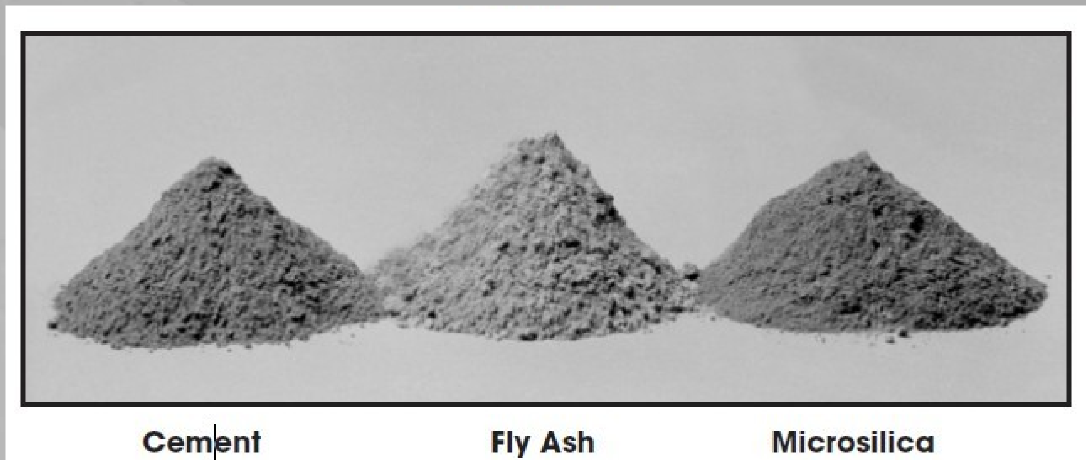
Cement constituents

Fly ashes

– obtained by electrostatic or mechanical precipitation of dust-like particles from flue gases from furnaces fired with pulverised coal

- **Siliceous fly ash (V)**
- **Calcareous fly ash (W)**



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Cement constituents

- **Burnt shale (T)**
  - specifically burnt oil shale at approximately 800 °C
- **Limestone (L, LL)**
  - $CaCO_3$ content ≥ 75 % by mass
- **Silica fume (D)** (microsilica)
  - originates from the reduction of high purity quartz with coal in electric arc furnaces in the production of silicon and ferrosilicon alloys (very fine spherical particles)

Cement classification

(EN 197-1)

CEM I 42,5 R

- **I** → **type**
- **42,5** → **strength class**
- **R** → **high early strength**

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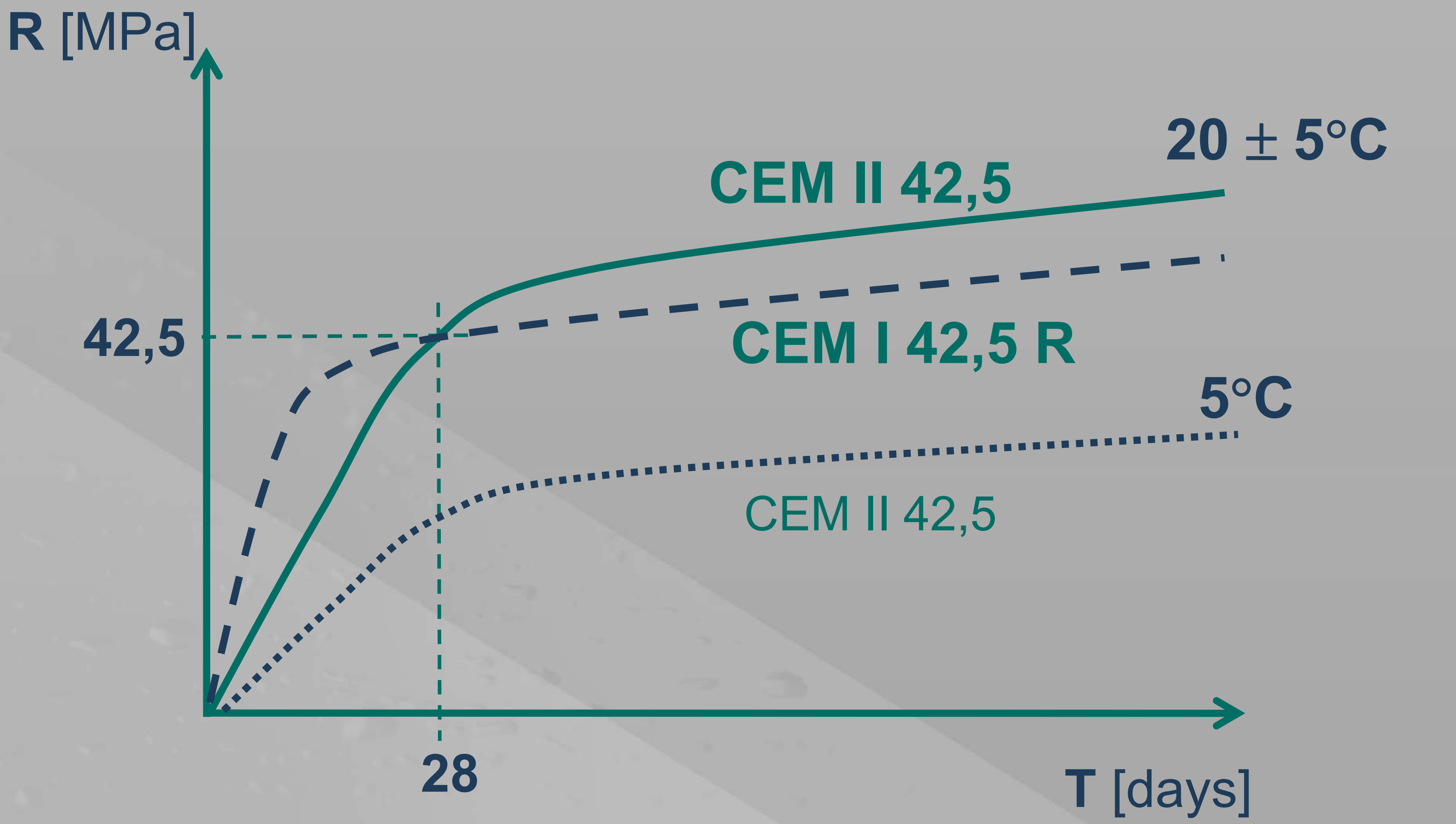
Strength classes of cement

- the **standard strength** of a cement is the compressive strength in MPa determined in accordance with EN 196-1 at 28 days
- three classes of standard strength:
  - **32,5**
  - **42,5**
  - **52,5**

Strength increase



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Properties of cement types

- **Portland cement**
  - high strength
  - fast increase of strength
  - big amount of hydration heat
- **Portland slag blastfurnace cement**
  - high sulphate resistance
  - low hydration heat
- **silica-fume cement**
  - low porosity of concrete
  - exceptionally high strength
- **fly-ash cement**
  - good workability,
  - lower concrete water content

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Use of Portland cement

- concretes with high strength
- reinforced and prestressed concrete
- demanding precast products
- constructions exposed to frost and deicing admixtures (air-entrained concretes)
- sprayed concrete (shotcrete)

Use of Portland composite cement

- common concretes, esp. ready-mixed
- common reinforced concrete construction
- massive concrete constructions (supporting walls, waterworks)
- not suitable in chemically aggressive environment and for frost-resisting constructions

Use of other cements

Blastfurnace cements:

- water-resisting constructions
- massive constructions

Composite cements:

- massive construction, fundaments eg.
- less demanding precast products

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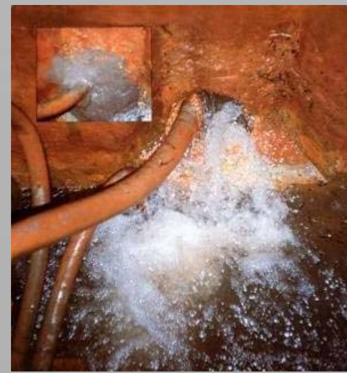
Special cements



- **expansive cement**
  - against drying shrinkage
- **fast repair cement**
- **sulphate resistant** - C_3A < 3,5%
- **white** - Fe < 1%
- **colored** - 5-10 % of pigments
- **strontium and barium cements**
  - Ba or Sr instead of Ca
  - high resistance to attack by sea water,
  - resistance to high temperatures
  - radiation shields

Masonry cement (MC)

EN 413-1

- for use in mortars for masonry construction
- lower strength

  MC5, MC 12,5, MC 22,5
- **can contain besides the portland cement lime, clay**

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Calcium aluminate cement

(High-alumina cement)

- consisting predominantly of hydraulic calcium aluminates
- over 35 % of Al_2O_3
- ultra - rapid strength development
- high chemical resistance
- refractory material (to 1750°C)

But !

- loss of strength due to „conversion“
- several failures in the 1970s

→ forbidden for the use in the bearing constructions !

Cement testing

EN 196 – Methods of testing cement

- 1 Determination of strength
- 2 Chemical analysis of cement
- 3 Determination of setting time and soundness
- 4 Quantitative determination of constituents
- 5 Pozzolanicity test for pozzolanic cement
- 6 Determination of fineness
- 7 Methods of taking and preparing samples of cement
- 10 Determination of the water soluble chromium (VI) content of cement
- 21 Determination of the chloride, carbon dioxide and alkali content of cement

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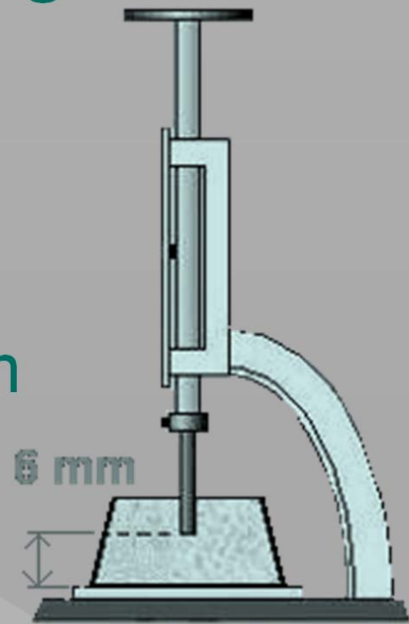
Testing of cements - terms

- **cement paste**
  - cement + water
- **cement mortar**
  - cement + water + **fine aggregates**
- **concrete**
  - cement + water + fine + **coarse aggregates**
- **water/cement ratio w/c**
  - mass of water/mass of cement
- **standard** (normal) **consistency**
  - the Vicat plunger penetrates 5 – 7 mm from the bottom of the mould



Determination of strength

(EN196-1)

compressive

$$R_t = \frac{F_{max}}{A}$$

flexural

(bending)

$$R_y = \frac{M_{max}}{W}$$

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Expression of test results of compressive strength

- **test set - 3 prism → 6 halves**
- arithmetic mean of the 6 individual result
- if one result within the 6 individual results varies by more than ± 10 % from the mean, discard this result and calculate the arithmetic mean of the 5 remaining results
- if one result within the 5 remaining results varies by more than ± 10 % from their mean, discard the set of results and repeat the determination

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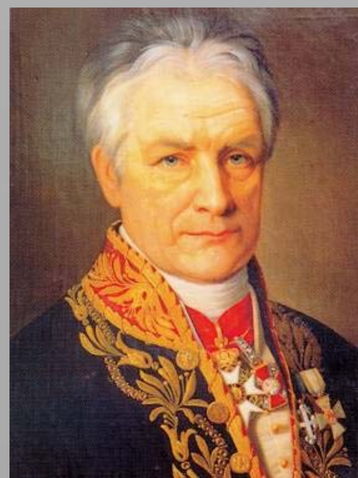
Chemical analysis of cement (EN196-2)

- loss on ignition
- residue insoluble
- determination of sulfate
- determination of major elements
  - silica
  - oxides Fe, Al, Ca, Mg
  - chloride
  - carbon dioxide
  - alkali

Setting time (EN196-3)

- **initial seting time**
- **final setting time**

Vicat apparatus



Louis **Vicat**
(1786 -1861)

Soundness (EN196-3)

- the ability of a hardened cement paste to retain its volume after setting without delayed destructive expansion caused by CaO or MgO

Henry Louis
Le Chatelier
(1850 - 1936)

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Quantitative determination of constituents (EN196-4)

- Portland cement clinker
- blastfurnace slag
- siliceous fly ash
- natural pozzolans
- limestone
- silica fume
- set regulators

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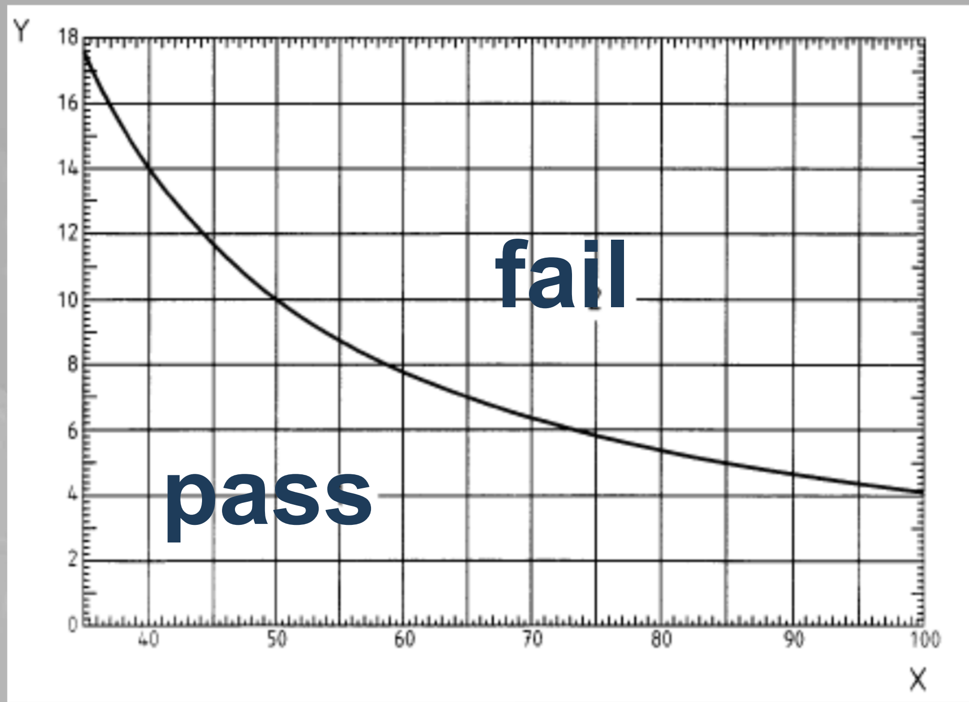
Pozzolanicity (EN196-5)

- comparing the concentration of calcium ion, expressed as CaO, present in the aqueous solution in contact with the hydrated cement, after a fixed period of time, with the quantity of calcium ion capable of saturating a solution of the same alkalinity



Calcium ion concentration [mmol/l]

Hydroxyl ion concentration [mmol/l]

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Finneness (EN196-6)

- **Blaine apparatus** (see Lecture 2)

$$S = \frac{K}{\rho} \times \frac{\sqrt{e^3}}{(1-e)} \times \frac{\sqrt{t}}{\sqrt{0{,}1\eta}}$$

Taking and preparing samples (EN196-7)

- from bags, containers, bulk, silos, filling machines
- quartering, sampling tube, screw sampler

Water soluble chromium (VI) content (EN196-10)

- hygienic and ecological properties

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Mechanical and physical requirements (EN197-1)

<table>
<tr><th rowspan="3">Strength class</th><th colspan="4">Compressive strength MPa</th><th rowspan="2">Initial setting time</th><th rowspan="2">Soundness (expansion)</th></tr>
<tr><th colspan="2">Early strength</th><th colspan="2">Standard strength</th></tr>
<tr><th>2 days</th><th>7 days</th><th colspan="2">28 days</th><th>minut</th><th>mm</th></tr>
<tr><td>32,5 N</td><td>-</td><td>≥ 16,0</td><td rowspan="2">≥ 32,5</td><td rowspan="2">≤ 52,5</td><td rowspan="2">≥ 75</td><td rowspan="6">≤ 10</td></tr>
<tr><td>32,5 R</td><td>≥ 10,0</td><td>-</td></tr>
<tr><td>42,5 N</td><td>≥ 10,0</td><td>-</td><td rowspan="2">≥ 42,5</td><td rowspan="2">≤ 62,5</td><td rowspan="2">≥ 60</td></tr>
<tr><td>42,5 R</td><td>≥ 20,0</td><td>-</td></tr>
<tr><td>52,5 N</td><td>≥ 20,0</td><td>-</td><td rowspan="2">≥ 52,5</td><td rowspan="2">-</td><td rowspan="2">≥ 45</td></tr>
<tr><td>52,5 R</td><td>≥ 30,0</td><td>-</td></tr>
</table>

Civilcrete
general purpose cement

Civilcrete complies with the chemical and physical requirements of SANS 50197 (EN197) for a Class IV 32,5R cement.

PHYSICAL PROPERTIES		
Property	**Civilcrete***	**EN Spec. requirement**
2 day *Compressive strength*	16,0 MPa	≥ 10,0 MPa
7 day *Compressive strength*	26,8 MPa	—
28 day *Compressive strength*	43,5 MPa	≥ 32,5 MPa
Initial set	197 minutes	≥ 75 minutes
Soundness	1,0 mm	≤ 10 mm

**Average test results*

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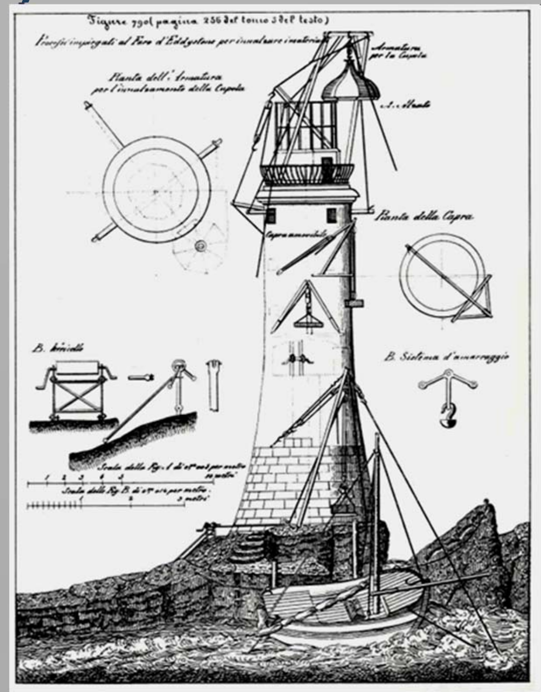
Hydraulic lime

- used by the Romans (100 B.C.)
  - (Plinus, Vitruvius)

    „Opus caementicium“
- forgotten in the middle age
- discovered again in the 18th century by burning **limestone containing clays**
  - 1756 – John Smeaton
  - 1796 - „roman cement“ (James Parker)
  - Louis Joseph Vicat



Eddystone Lighthouse

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Hydraulic lime

Raw material:

- **argillaceaous** (= containing clays) **limestones** → **natural hydraulic lime** (NHL)
- **quick lime** (burned limestone) + **pozzolanic** materials → **hydraulic lime** (HL)

Pozzolanic materials (pozzolans):

- consist mainly from reactive silica (SiO_2) and alumina (Al_2O_3)
- when finely ground and in the presence of water, they react with dissolved $Ca(OH)_2$
- volcanic ash, fly ash, silica fume, high-reactivity metakaolin, ground granulated blast furnace slag

Hydraulic lime manufacture

Natural hydraulic lime (NHL):

- burning of raw materials at the temperature **under 1250 °C**
- slaking (only when HM > 3)

Hydraulic lime (HL):

- grinding of quicklime together with pozollans

Hydraulic lime

- **in contrast to portland cement has higher amount of the free CaO and no alite (C_3S)** $\rightarrow$ lower strength than cement

According the degree of hydraulicity (hydraulic modulus):

- **feebly hydraulic lime** (HM 6 - 9) - need slaking
- **moderately hydraulic lime** (HM 3 - 6) – need slaking
- **eminently hydraulic lime** (HM 1,7 - 3) – does not need slaking

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Natural hydraulic lime - EN 459

Type	SO_3 (mass %)	Free lime (mass %)	Strength after 28 days [MPa]
NHL 1	≤ 2	≥ 50	≥ 0,5 - ≤ 3
NHL 2	≤ 2	≥ 40	≥ 2 - ≤ 7
NHL 3,5	≤ 2	≥ 25	≥ 3,5 - ≤ 10
NHL 5	≤ 2	≥ 15	≥ 5 - ≤ 15

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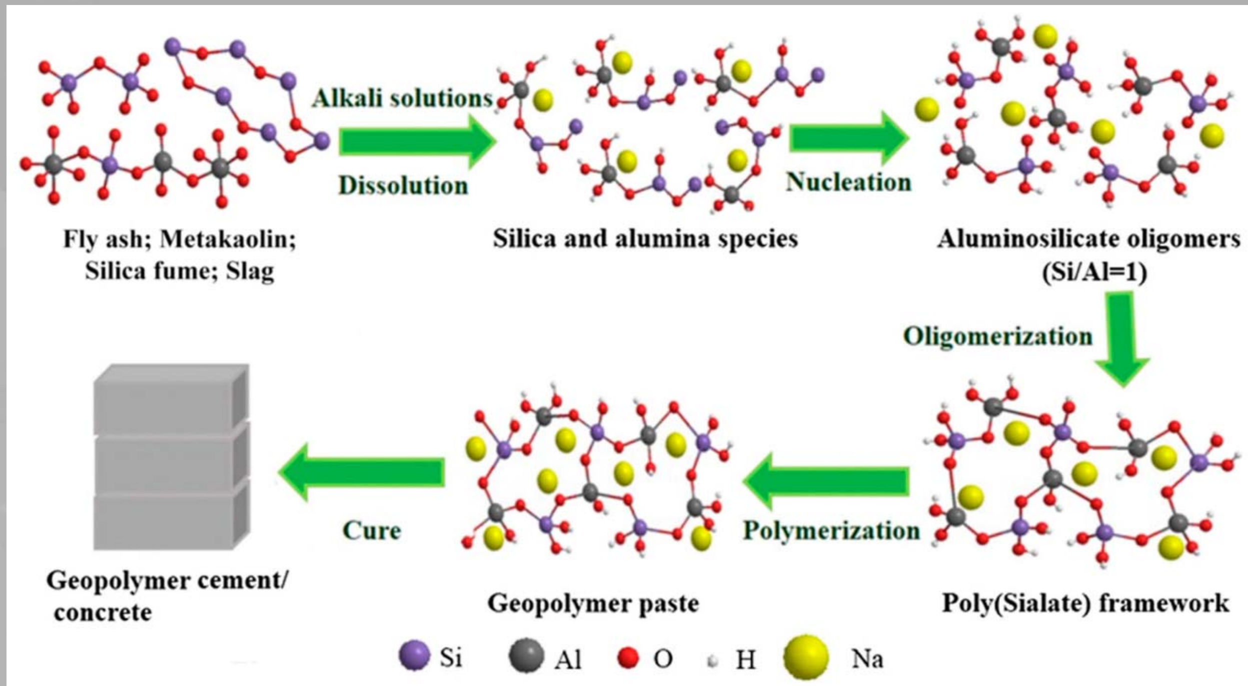
Hydraulic lime use

- **monuments renovations**
  - better breathing of walls
  - moisture can evaporate
  - mortars and renders do not set too hard
  - expansion joints can often be avoided
  - reduced condensation
  - no salt staining

Using of cement with old bricks

Geopolymers

- synthetic aluminosilicate polymers formed in alkaline environment at normal temperature
- raw material – pozzolans, e.g. thermaly activated clays (metakaolin), fly ash + strong alkali activator



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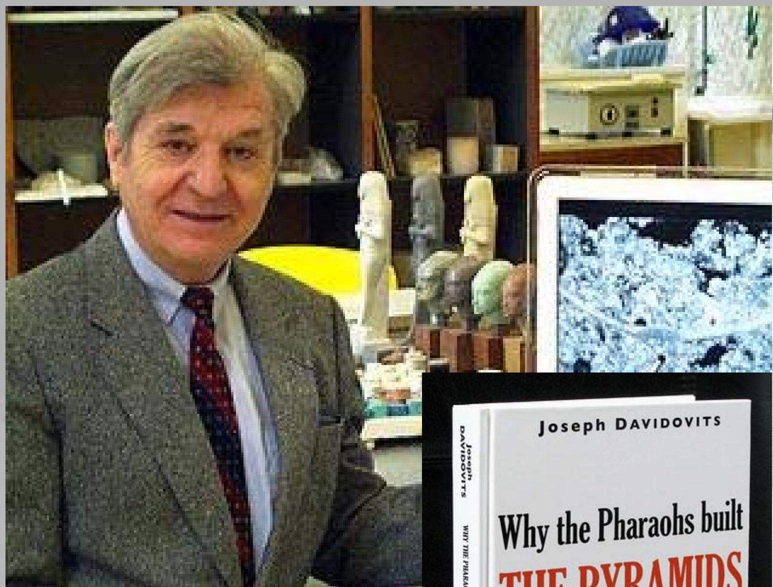
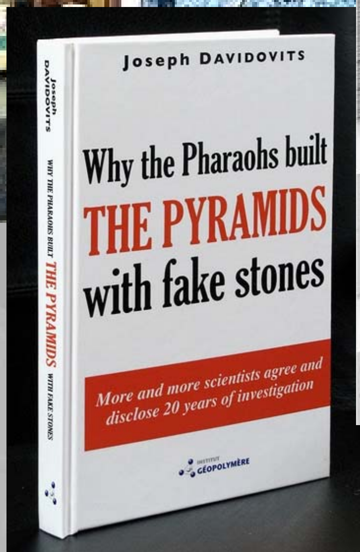
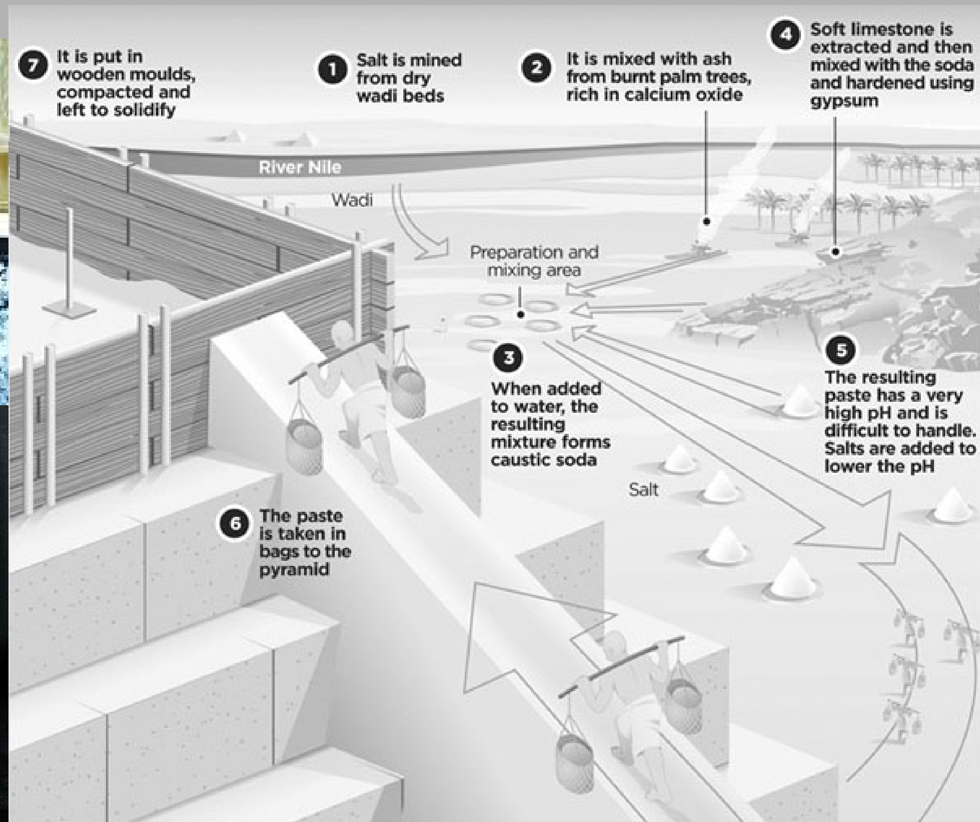
Geopolymers

- Prof. Joseph Davidovits







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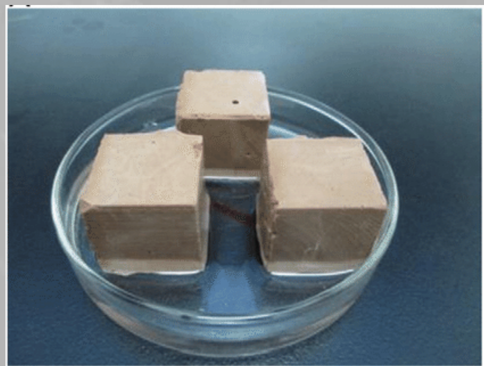
Video:
https://www.geopolymer.org/archaeology/pyramids/pyramids-4-videos-download-chapter-1/

Geopolymer concretes

+ high strength
+ fire resistant
+ lower energy consumption
+ chemically resistant
+ durability
+ utilization of wastes

- price
- efflorescence
- difficult preparation (some alcali activators are harmfull)
- worse workability



Geopolymers - use

- repair of damaged concrete
- fire protection systems
- building chemistry (sealants, heat systems)
- fixation of heavy metals and radioactive waste
- restoration
- imitation of natural materials

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Non-hydraulic binders

- **gypsum binder**
- **anhydrite binder**
- (non-hydraulic) **lime**
- **water glass**
- **magnesium binder**

Calcium sulphate binders

- contain calcium sulphate ($CaSO_4$)
  a) **gypsum binder** (= plaster of Paris)
  b) **anhydrite binder**

Raw materials:

a) calcium sulphate dihydrate
   - $CaSO_4 \cdot 2H_2O$

b) calcium sulphate anhydrite
   - **$CaSO_4$**

Giant gypsum rock crystals, Naica mine, Mexiko

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Gypsum binder - raw materials

- natural rock (selenite, alabaster, satin spar…)
- **FGD gypsum**
  - synthetic product from **F**lue **G**as **D**esulfurization systems at coal power stations
- phosphogypsum
  - by-product of processing phosphate ore into fertilizer with sulfuric acid
- citrogypsum
- titanogypsum

Gypsum binder

- calcium sulphate hemihydrate

$CaSO_4 \cdot 0,5H_2O$

- one of the oldest binders
  - Anatolia and Syria – 5000 b.C.
  - Egyptians
  - Greeks
  - Romans

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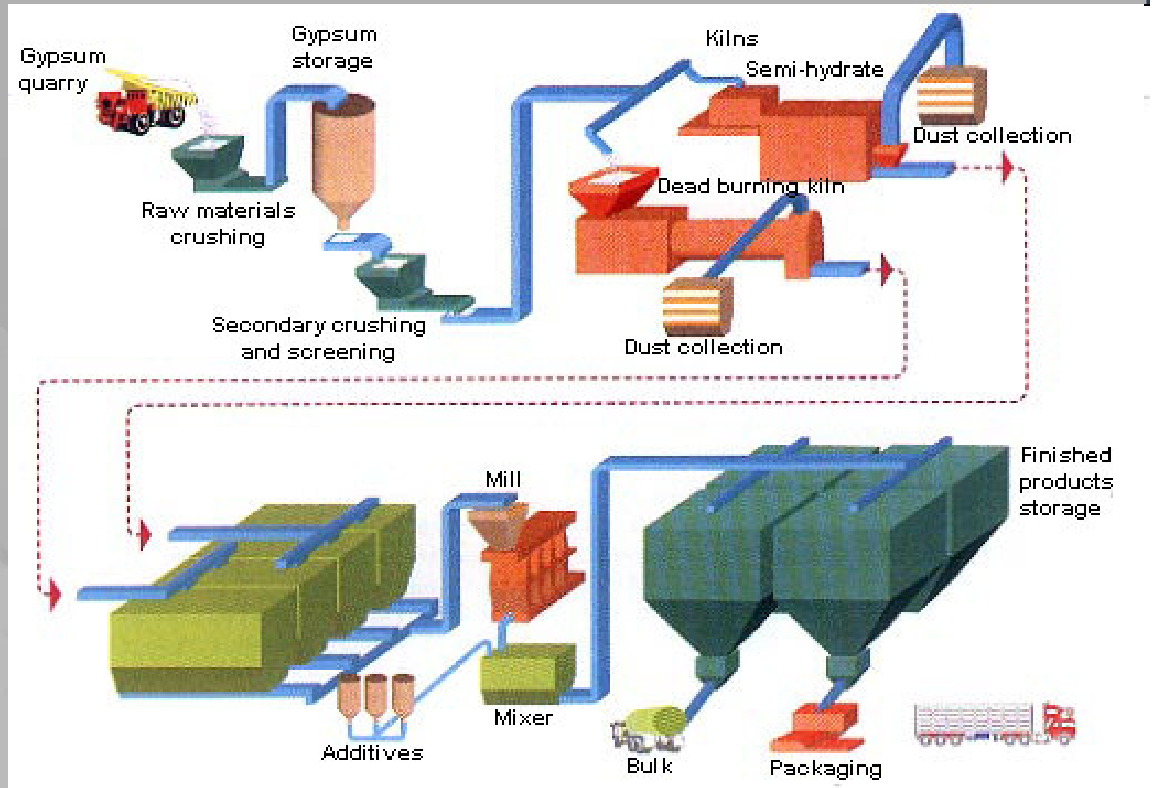
Gypsum binder manufacture

- **calcination** (150 – 180 °C)

$$CaSO_4 \cdot 2H_2O \xrightarrow{\text{heat}} CaSO_4 \cdot 0{,}5H_2O + 1{,}5H_2O$$



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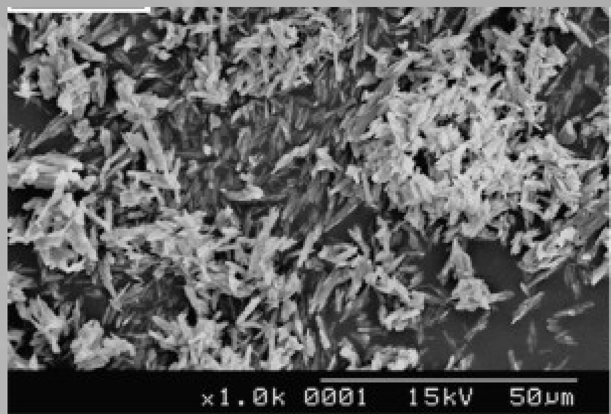
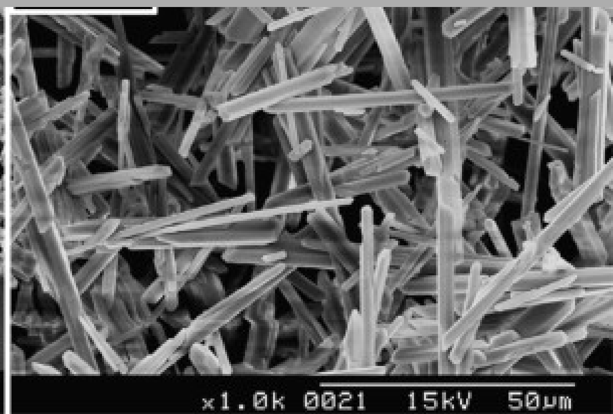
Gypsum binder types

According production process:

- **β - gypsum**
  - production at high temperature in normall air pressure
- **α- gypsum**
  - production at high temperature and high steam pressure in autoclave





Gypsum crystals: β - **gypsum** α - **gypsum**

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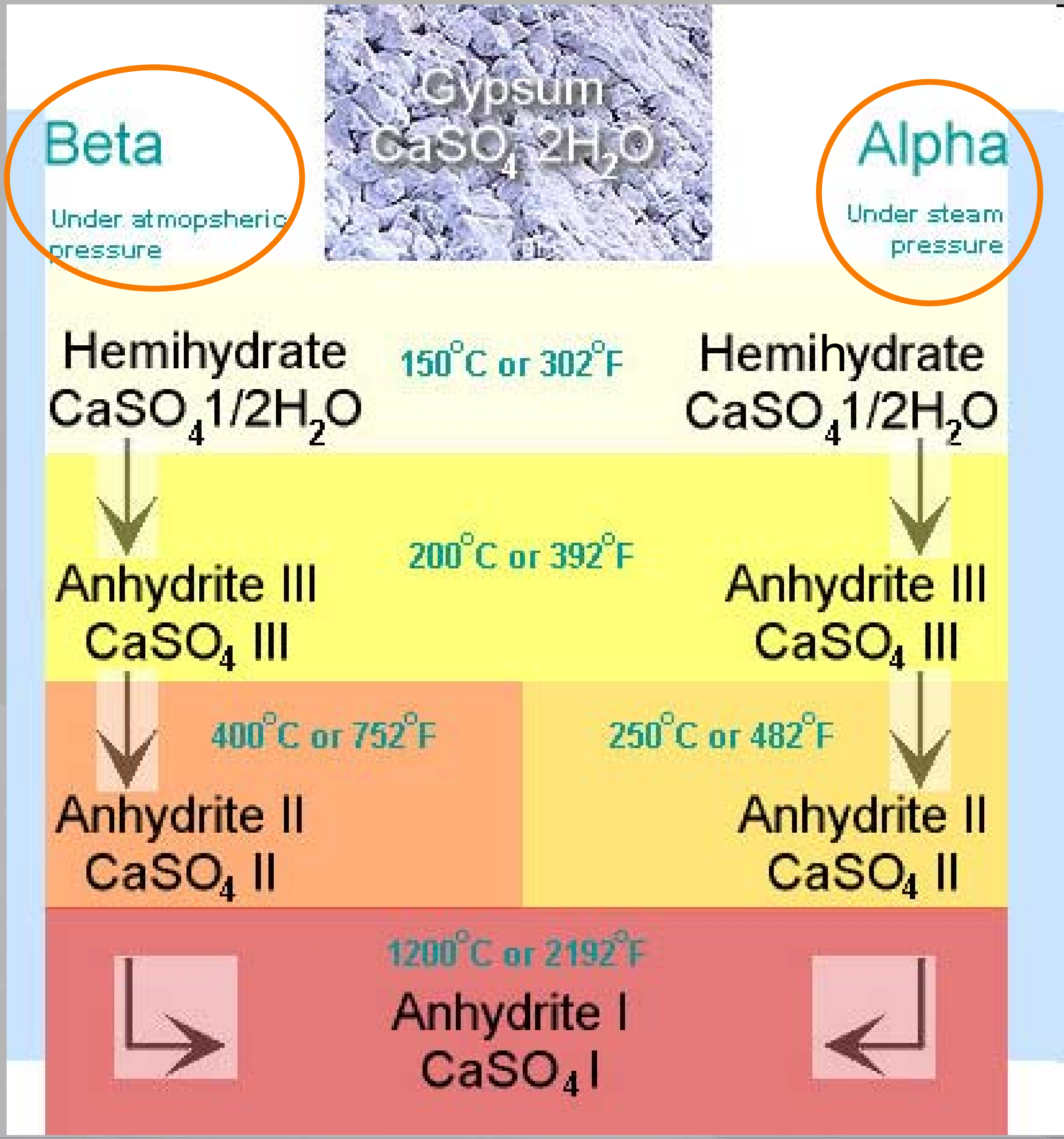
Gypsum dehydration



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Difference between α a β gypsum

- chemically identical ($CaSO_4 \cdot 0{,}5H_2O$), but different properties

	β - gypsum	α- gypsum
Particle size	1 – 5 μm	10 – 20 μm
Particle porosity	high	low
Specific surface	big	small
Strength increase	fast	slower
Final strength	lower	higher

Gypsum setting and hardening

$CaSO_4 \cdot 0{,}5H_2O + 1{,}5H_2O \rightarrow CaSO_4 \cdot 2H_2O$

Initial setting:

- due to a colloidal mechanism or action of capillary forces causing a packing together of hemi-hydrate particles

Hardening and final setting

- a crystallization process

EN 13 279 - Gypsum binders and gypsum plasters. Definitions and requirements

Table 3 — Requirements for gypsum plasters

<table>
<tr><th rowspan="2">Gypsum plasters</th><th rowspan="2">Gypsum binder content %</th><th colspan="2">Initial setting time min</th><th rowspan="2">Flexural strength N/mm²</th><th rowspan="2">Compressive strength N/mm²</th><th rowspan="2">Surface hardness N/mm²</th><th rowspan="2">Adhesive strength N/mm²</th></tr>
<tr><th>manual gypsum plaster</th><th>projection gypsum plaster</th></tr>
<tr><td>B1</td><td>≥ 50</td><td rowspan="7">> 20[b]</td><td rowspan="7">> 50</td><td rowspan="6">≥ 1,0</td><td rowspan="6">≥ 2,0</td><td rowspan="6">–</td><td rowspan="7">Fracture occurs within the background or the gypsum plaster, when fracture occurs in interface gypsum/background the value shall be ≥ 0,1.</td></tr>
<tr><td>B2</td><td><50</td></tr>
<tr><td>B3</td><td>a</td></tr>
<tr><td>B4</td><td>≥ 50</td></tr>
<tr><td>B5</td><td><50</td></tr>
<tr><td>B6</td><td>a</td></tr>
<tr><td>B7</td><td>≥ 50</td><td>≥ 2,0</td><td>≥ 6,0</td><td>≥ 2,5</td></tr>
<tr><td colspan="8">a According to 3.3, 3.4, 3.5 and 3.6</td></tr>
<tr><td colspan="8">b For some manual applications a lower value than 20 min is permitted. In that case the initial setting time shall be declared by the producer</td></tr>
</table>

Modification of gypsum properties

- setting retarders (citric acid, molasses, blood, saliva, agar)
- setting accelerators (hardened gypsum = calcium dihydrate)
- fungicides
- hydrophobic additives
- pigments
- plasticizers (Althaea officinalis - Marshmallow root)
- reinforcement (glass fibers, animal hairs)

Althaea officinalis

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Strength of gypsum

Depends on:

- **moisture content**
  - with increasing moisture the strength decreases
- **water/gypsum ratio**
  - with increasing w/g the strength decreases

Conditioning	Moisture in gypsum	Compressive strength	
	%	MPa	%
Dried at 35 - 40 °C	0	13,8	100
In air with 65 % RH	0,04	13,6	98,5
In air with 90 % RH	0,15	12,9	93,5
Immersed in water	17,50	6,4	46,5

w/g	Bulk density	Compressive strength
	$kg.m^{-3}$	MPa
0,50	1410	14,6
0,55	1300	13,0
0,60	1230	11,4
0,65	1170	10,8
0,75	1040	9,5

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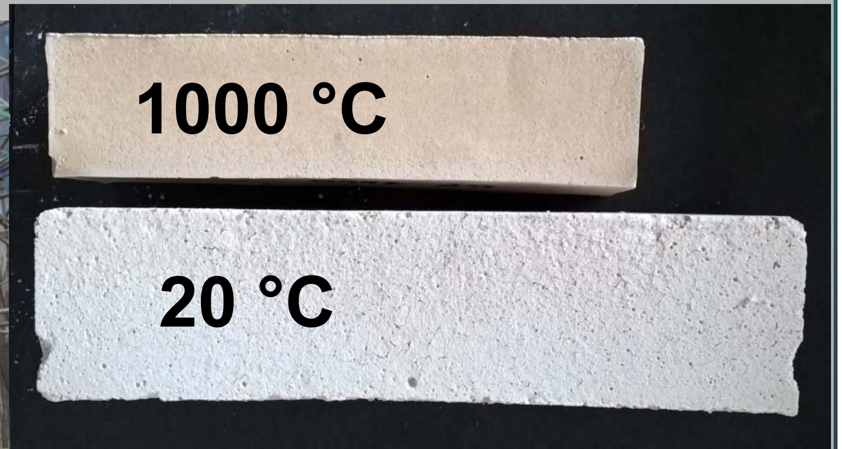
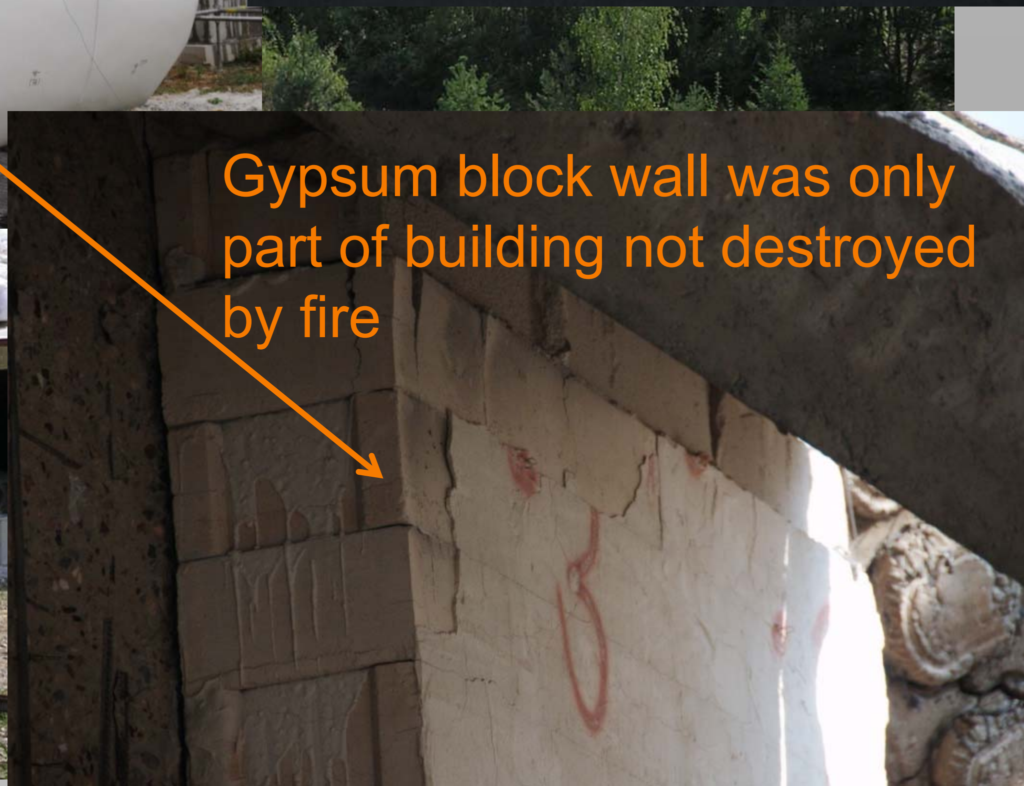
Gypsum fire resistance

- **non – flammable** (class A1)
- contains water of crystallization (17 % of its weight)
- exposed to the fire, the chemically combined water is released in the form of water vapor → the dehydration (calcination) of gypsum occurs
- calcined gypsum adheres to the uncalcined material and retards the further calcination process
- until all the water of crystallization has been liberated, the temperature on the unexposed side will not exceed 100°C
- **gypsum can serve as a fire retardant** with ability to delay the spread of fire up to 4 hours → protection of wood and steel elements against fire

Gypsum after fire test





Gypsum block wall was only part of building not destroyed by fire

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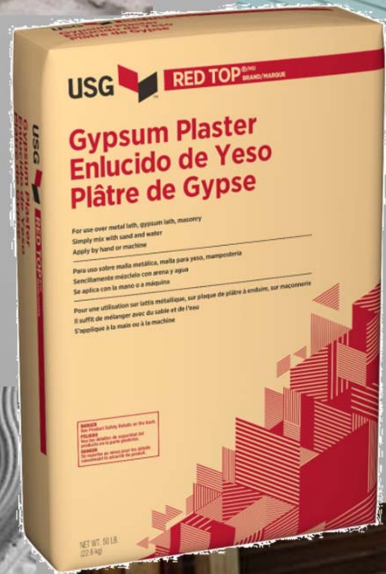
Gypsum uses

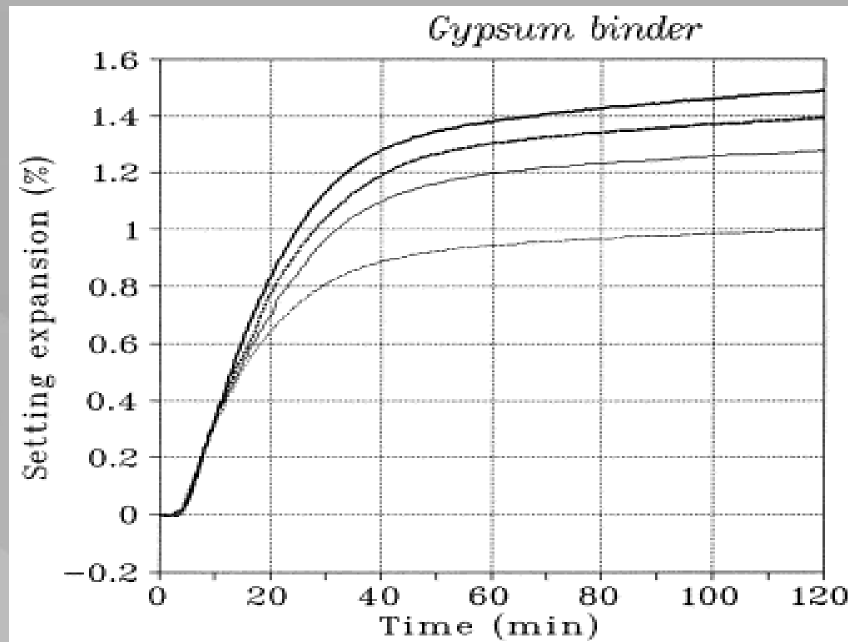
Interior only

- plasters
- blocks
- floor screeds
- gypsum boards (drywall)
- gypsum fiberboards



Lime - gypsum plaster

- gypsum sets quickly, lime is slow to set → combination of lime and gypsum plasters sets at a medium speed
- while setting, gypsum plaster expands slightly and lime contracts slightly → the plaster does not crack
- better workability



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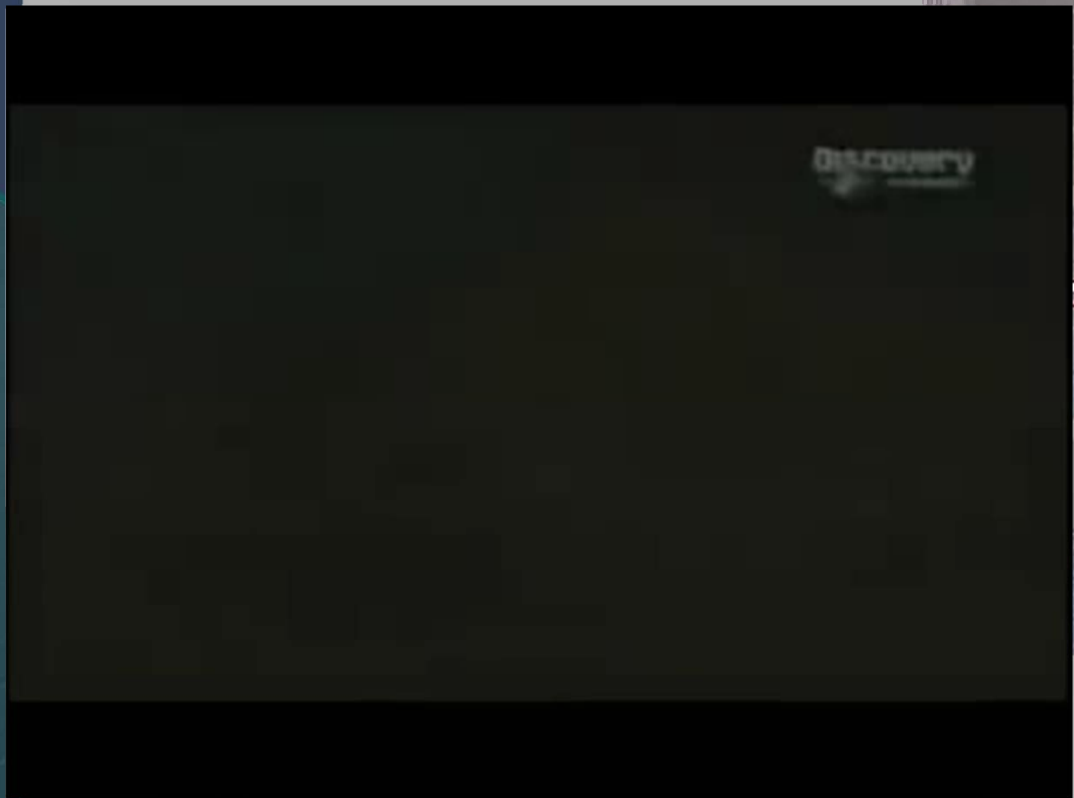
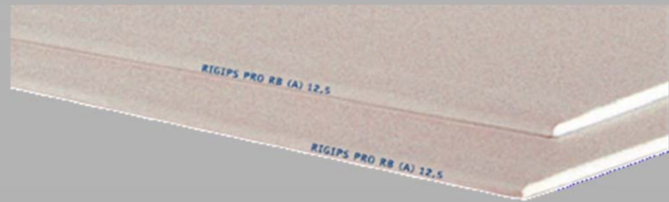
Gypsum board (drywall)

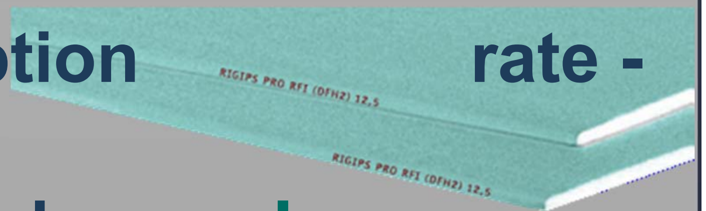
- panel made of a paper liner wrapped around an inner core made from gypsum with fibers (cellulose and/or fiberglass)



Gypsum board types

- **Gypsum plasterboard** - type **A**
- G. p. with **control density** - **D**
- Gypsum sheathing board - **E**
  - in external walls. reduced water absorption rate with a minimum water vapor permeability
- G. p. with **improved core adhesion at high temperatures** - **F**
  - mineral fibers and / or other additives in the gypsum core
- G. p. with **reduced water absorption rate** - **H1 – H3**
- G. p. with **enhanced surface hardness** - **I**
- G. **baseboard** - **P**
- G. p. with **enhanced strength** - **R**





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Special gypsum boards

- **fire proof (F)**
  - glass fibre and other additives in the core
- **acoustic** (D)
  - high density core
  - special dimensional configuration
- **thermal insulating**
  - bonded to an expanded polystyrene

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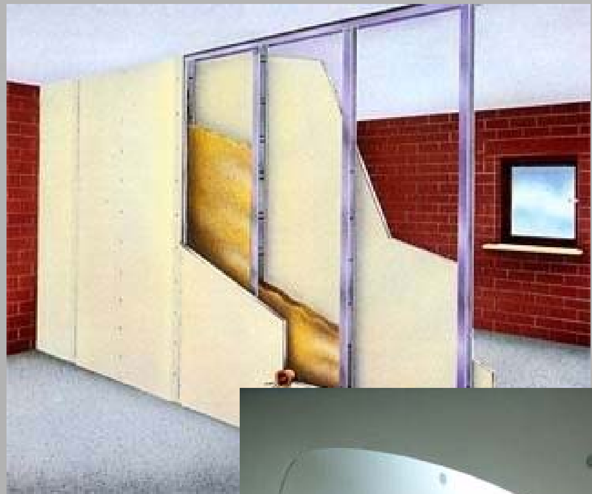
Gypsum board use

- standard boards – to 65%RH
- impregnated boards –
  permanently to 75 %RH
  for a short term to 100 %



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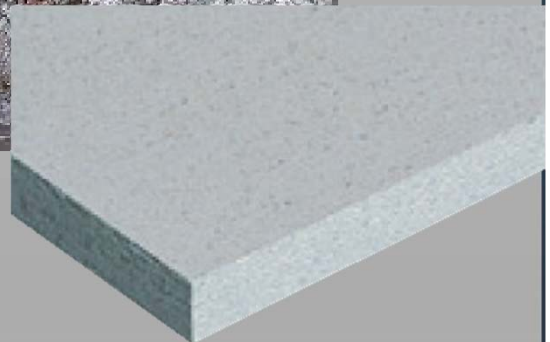
~~Basement, showers~~

Gypsum fiberboards

- gypsum (80%) + cellulose fibers (20 %)
  - no paper on surface
  - higher bulk density
  - higher strength
  - better fire resistance
  - in the higher humidity



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Anhydrite

- **anhydrous $CaSO_4$**
  - needs activator to set
- activators: lime, cement, sulphates
- slow setting even with activator
- used for „self-leveling“ screeds

Self-leveling screeds

- contains gypsum or anhydrite + plasticizer + sand (1:1 – 1:2)
- very good for under-floor heating
- used in interiors only

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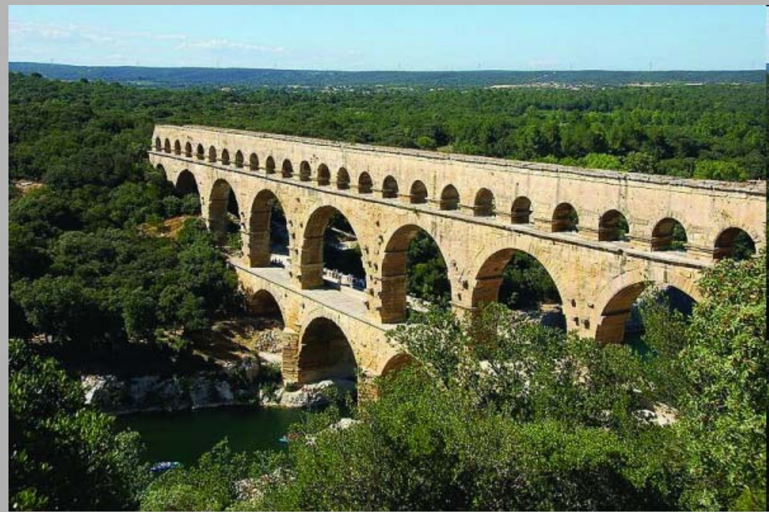
Air (non hydraulic) **lime**



- calcium oxide **CaO** or calcium hydroxide **$Ca(OH)_2$** with different purity
- known from ancient days (Assyrians, Egyptians, Greeks, Romans.....)

Building limes classification

- **EN 459 Building lime**
  - **Air lime**
    - Calcium lime
    - Dolomitic lime
  - **Hydraulic lime**
    - Hydraulic lime HL
    - Natural hydraulic lime NHL

Air lime manufacturing

Raw material:

- **limestone, calcite, chalk** ($CaCO_3$)
- **dolomitic limestone** ($CaCO_3$+$MgCO_3$)
- **dolomite** ($CaCO_3 \cdot MgCO_3$)

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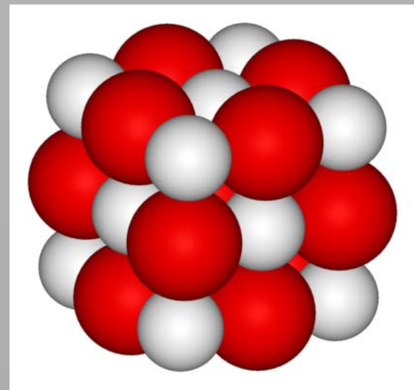
Air lime manufacturing

Air lime manufacturing

- step 1 – **burning** (decarbonation) → **quicklime CaO**
  - crushed, ground, pulverized
  - unstable in the presence of moisture and CO_2



- step 2 – **slaking** (hydration)→ **hydrated lime $Ca(OH)_2$**
  - lime water, slurry, putty, milk of lime
  - powder

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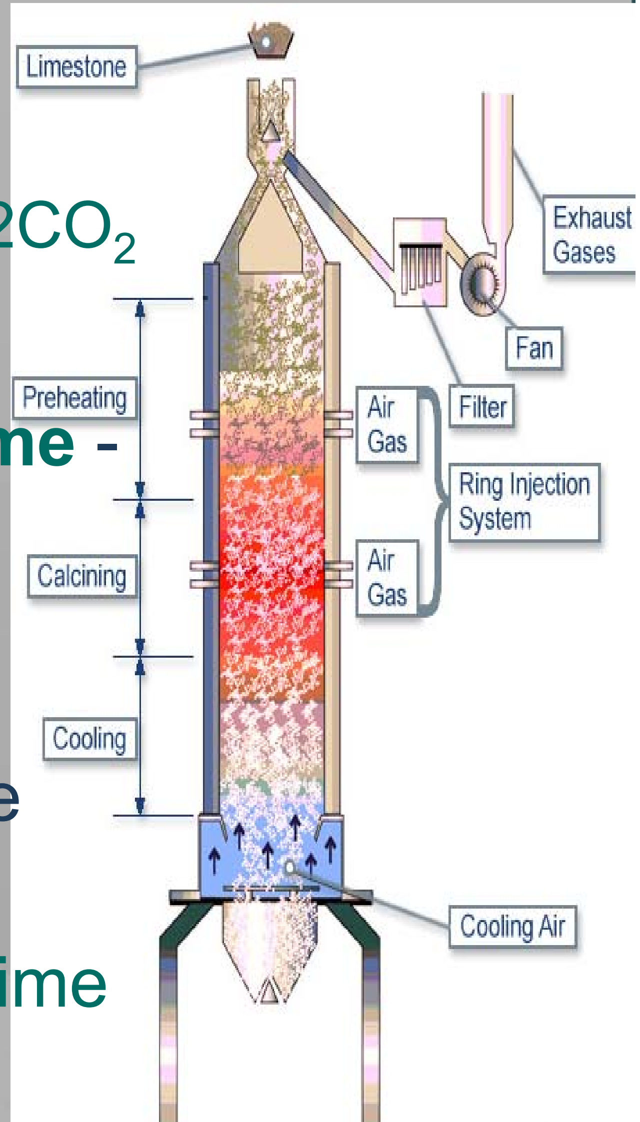
Air lime burning

- **900 - 1200°C** $\rightarrow$ decarbonation in **kilns**

$$CaCO_3 \xrightarrow{heat} CaO + CO_2$$

$$CaCO_3 \cdot MgCO_3 + heat \rightarrow CaO + MgO + 2CO_2$$

- lower temperature - **soft-burned lime** - more reactive, porous, suitable for mortars
- higher temperature – **hard-burned lime** – less reactive, denser, suitable for AAC
- too high temperature – overburned lime



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Lime kilns

- traditional

Pacold lime kiln, Prague

Crypta Balbi, Roma

- contemporary

Rotary kiln

Vertical kiln

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Quicklime CaO

- large lump lime
- crushed lime < 25 mm
- ground lime < 2,5 mm
- pulverized lime < 0,2 mm
- pelletized lime

Quicklime hydration

Reaction between quicklime and water:

$$CaO + H_2O \rightarrow Ca(OH)_2 + heat$$

- highly exothermic process

Types of hydration:

- **dry hydration** → $Ca(OH)_2$ in powder
- **slaking** → $Ca(OH)_2$ in suspension (slurry, putty, limewater)

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Quicklime slaking

- **CaO reacts with the amount of water much higher than the quantity, necessary for the reaction**
- **240-320 l** of water /**100 kg** of quicklime
- **limewater, putty, slurry, milk of lime** (= aqueous solution of $Ca(OH)_2$)
- a great quantity of heat is r
  → material can splatter
  → **danger of burns!**

Quicklime slaking

- **the volume expansion** (due to absorbed water) - the greater the expansion, the better lime
  - min. **2,6 l** slurry **from 1 kg** of quicklime

- the lime putty has to **mature** (few hours to many days) to allow the slaking of all particles
  - historically lime was slaked over a period of at least six months (even 10 years)

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Quicklime slaking

Factors affecting the slaking process:

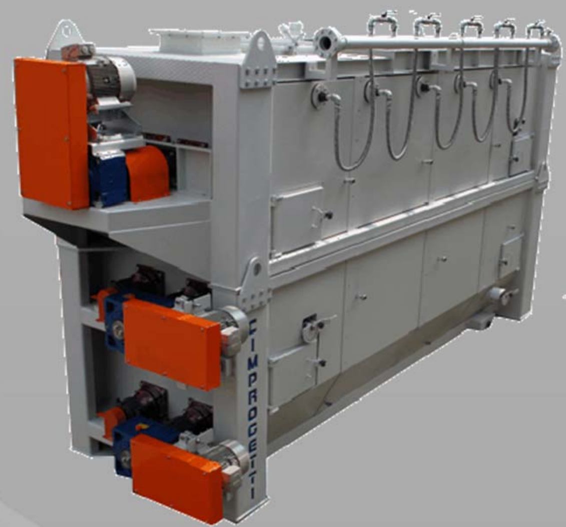
- quality of quicklime
- specific surface
- temperature (slightly under 100 °C)
- amount of water added
  - to much water → drowning (killing) the lime

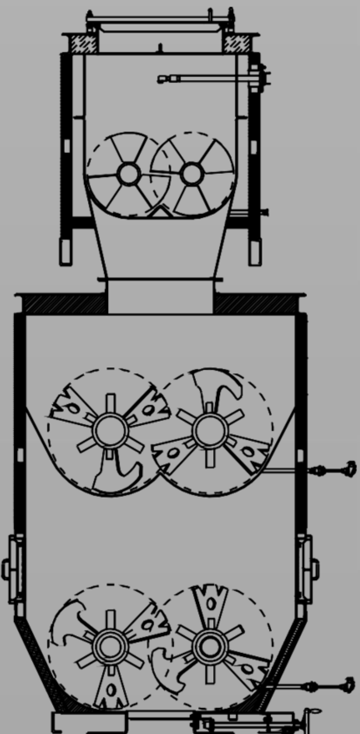
Imperfect slaking:

- **uneconomical** (unskillful slaking may reduce the paste to less than two volumes)
- the **unslaked particles** may slake later in the mortar

Dry hydration of quicklime

- adding water under controlled conditions
- reaction with just the right amount of water
- **65 –70 l** of water / **100 kg** of quicklime
- **powder hydrated lime** ($Ca(OH)_2$)





- special equipment - lime **hydrator**

- lime putty (powder + water) has to **mature**

Setting and hardening of air lime

- **Setting** – physical reaction (drying out of colloid gel)
- **Hardening** – **carbonation**

$Ca(OH)_2 + CO_2 + nH_2O \rightarrow \mathbf{CaCO_3} + (n+1)H_2O$

- slow
- depends on CO_2 concentration and RH and air temperature

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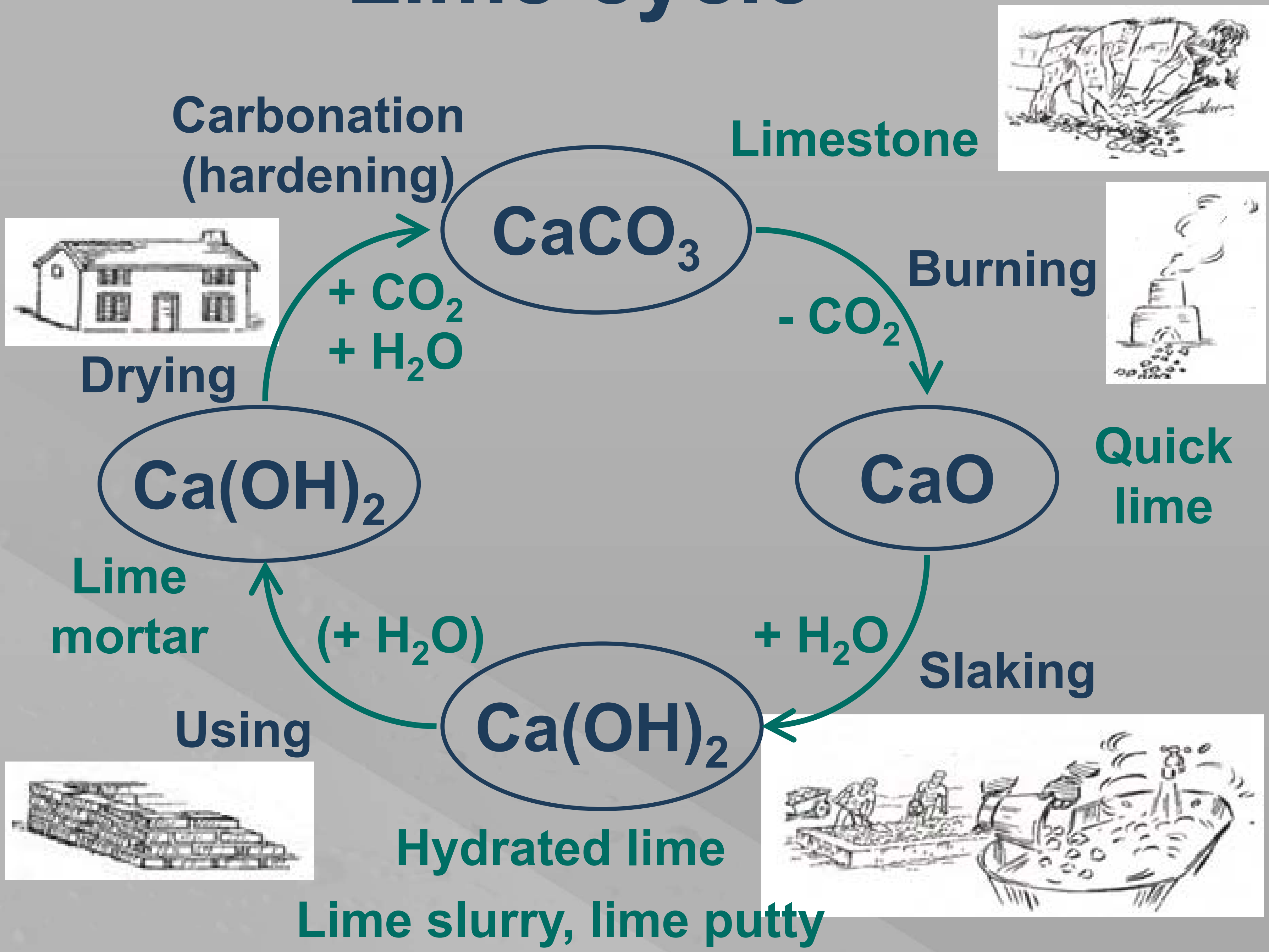
Lime cycle

Lime cycle



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Air lime use

- **mortars and plasters**
  - prepared in-situ
  - ready-made mixtures

- lime wash – white or color paint

- disinfectant

- autoclaved **sand lime bricks**
- autoclaved **aerated concrete**

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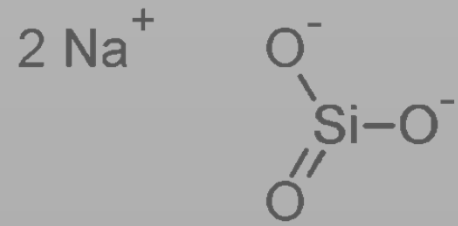
Water glass

Sodium silicate – aqueous solution or solid compound of sodium oxide (Na_2O) and silica (silicon dioxide, SiO_2)



- **sodium,** potassium, lithium
- produced by burning of soda ash (Na_2CO_3) and silica sand (SiO_2) in a furnace (1000 - 1400 °C) or dissolving silica sand under pressure in a heated aqueous solution of soda (NaOH)
- **hardening**: adding of the weak acids (CO_2, organic esters)
- usually mixed with fine sand

Water glass use

- **timber treatment** – wood preservation
- **binders** exposed to heat or fire
- **concrete and masonry treatment** – reducing of their porosity
- **refractory use** - with lightweight aggregates
- **water treatment**
- soil stabilization

Magnesia binder

- **Sorel cement**
- based on **MgO** and **$MgCl_2$**
- prepared by mixing burned magnesia (MgO) with magnesium chloride
- **hardening** – formation of magnesium oxychlorides
- high strength
- good fire resistance
- good resistance to abrasion
- high elasticity

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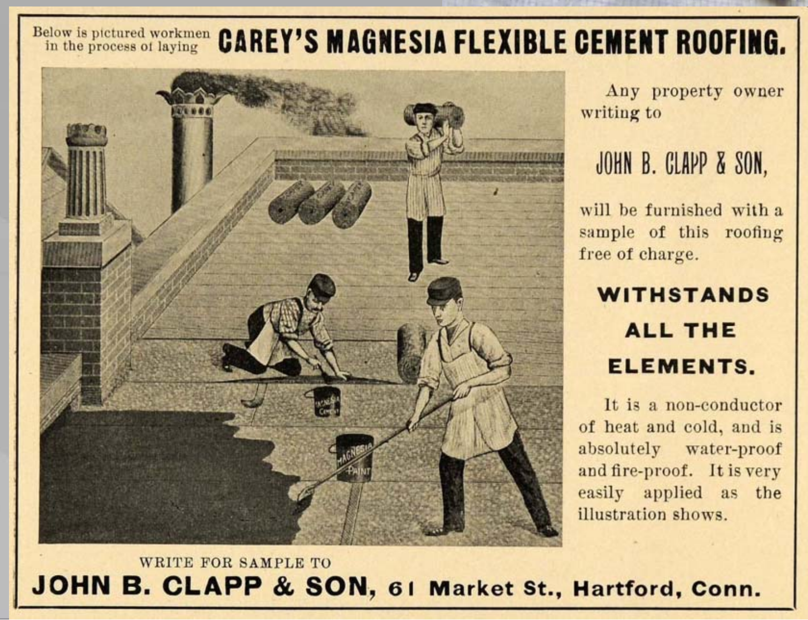
Magnesia binder use

- floorings (cast floors)
  - **Xylolith**
- fire protection products
- fiber boards
- grinding wheels,
- abrasive stones



Xylolith

- mixture of magnesia cement, sawdust, and wood flour, with an addition of finely dispersed mineral substances (talc, asbestos, marble flour) and alkali-resistant pigments
- the seamless floors in residential and public buildings

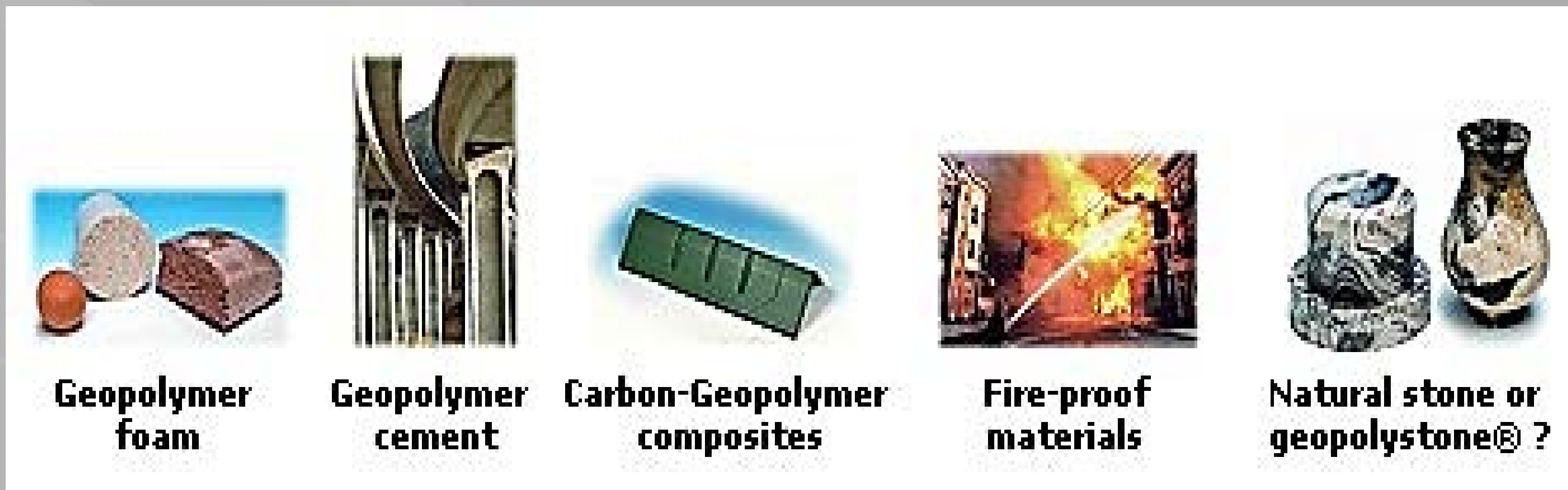
Villa **Tugendhat**, Brno
Ludwig **Mies van der Rohe**, 1930

Geopolymers

- synthetic aluminosilicate polymers formed in alkaline environment at normal temperature
- raw material – pozzolans, e.g. thermaly activated clays (metakaolin), fly ash + strong alkali activator

Eohhglqj#ri#Frqfuhwhb{ylg1dyl

- fire-resistant, blast-resistant and acid-resistant



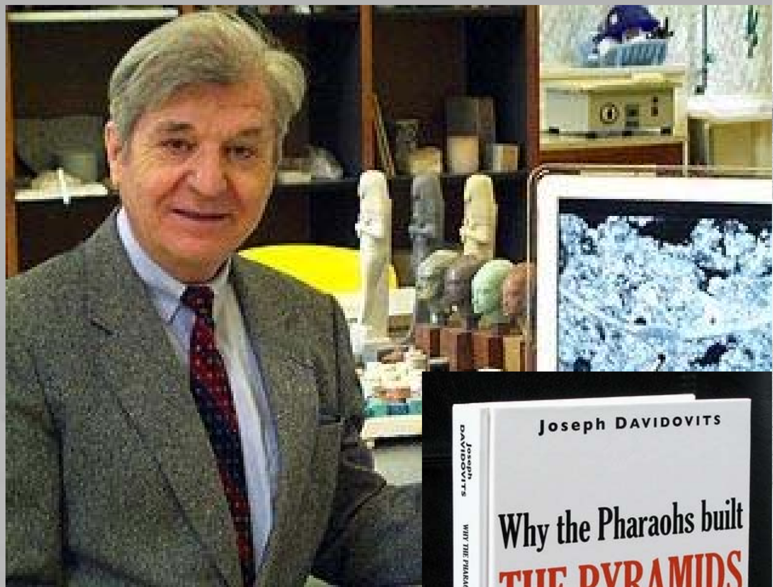
Pozzolanic materials

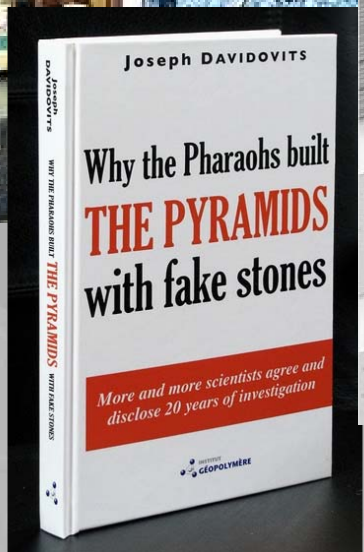
- contain active silica (SiO_2)
- not cementitious in itself but will, in a finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form cementitious compounds
- silica must be glassy and amorphous

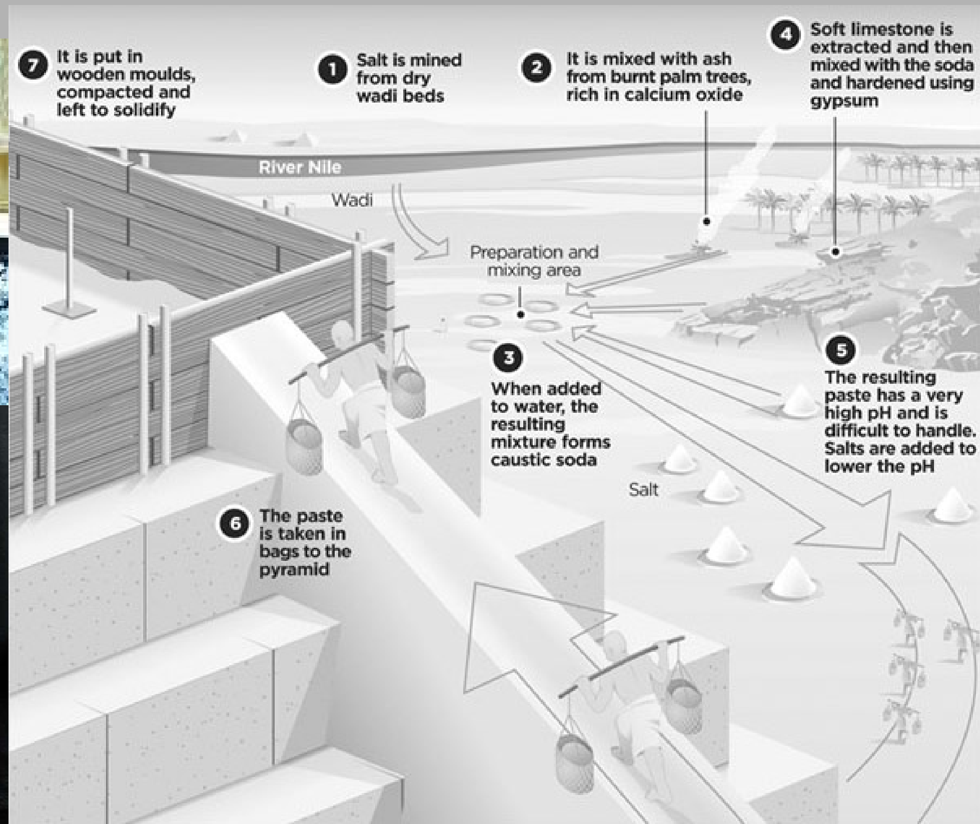


Geopolymers

- Prof. Joseph Davidovits







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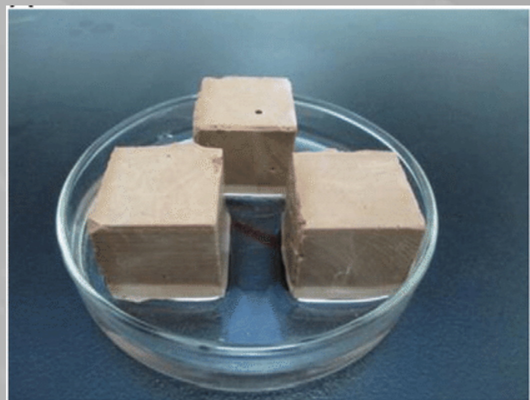
Video:
https://www.geopolymer.org/archaeology/pyramids/pyramids-4-videos-download-chapter-1/

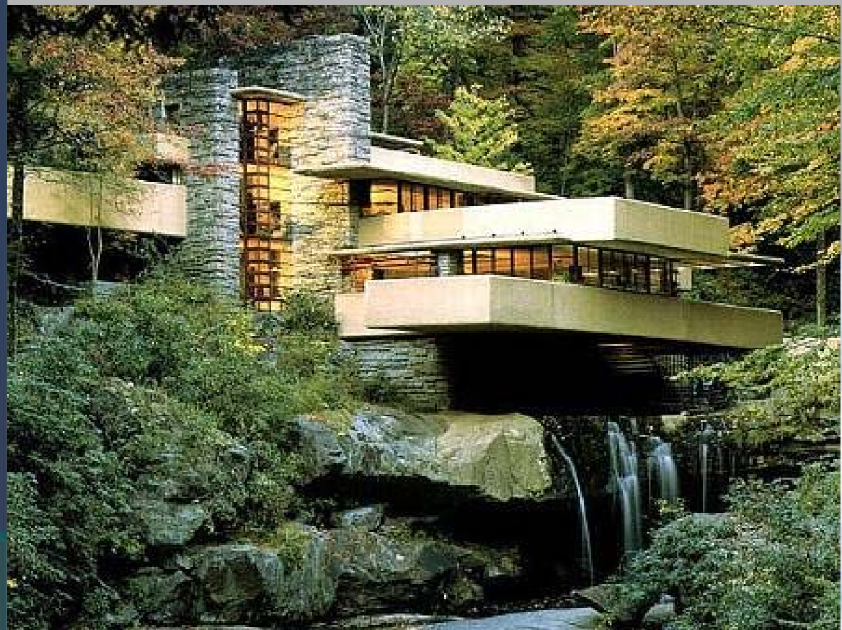
Geopolymer concretes

+ high strength
+ fire resistant
+ lower energy consumption
+ chemically resistant
+ durability

- price
- efflorescence
- difficult preparation



Concrete



Fallingwater, Pennsylvania
Frank Lloyd Wright, 1939

Dancing house, Prague
V. Milunić, F. Gehry, 1996

Petronas Twin Towers, Kuala Lumpur
César Antonio Pelli, 1999

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Concrete

EN 206-1 Concrete - Part 1: Specification, performance, production and conformity:

- material formed by mixing **cement**, **coarse** and **fine aggregate** and **water**, with or without the incorporation of **admixtures** and **additions**, which develops its properties by **hydration** of the cement

Concrete components

- **binder** (cement)
- **aggregates**
- **mixing water**
- admixtures (up to 5 % of cement mass)
- additions (in powder, 5 - 40%)
- reinforcement (steel bars, grids, fibers)

Terms (EN 206-1)

- **fresh concrete -** concrete which is fully mixed and still in a condition that is capable of being compacted by the chosen method

- **hardened concrete -** concrete which is in a solid state and which has developed a certain strength

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Terms (EN 206-1)

- **designed concrete** (most common) **-** concrete for which the **required properties** and additional characteristics **are specified to the producer** who is responsible for providing a concrete conforming to the required properties and additional characteristics
- **prescribed concrete** (used rarely) **-** concrete for which the **composition** of the concrete and the constituent materials to be used **are specified to the producer** who is responsible for providing a concrete with the specified composition

Concrete types according the bulk density

- **normal weight concrete**

  2000 –2600 kg.m^{-3}

- **light-weight concrete**

  800 – 2000 kg.m^{-3}

- **heavy-weight concrete**

  > 2600 kg.m^{-3}

Concrete types according the place of manufacture

- **site-mixed concrete -** concrete produced on the construction site by the user of the concrete for his own use
- **ready-mixed concrete -** concrete delivered in a fresh state by a person or body who is not the user. Ready- mixed concrete is also:
  - concrete produced off site by the user
  - concrete produced on site, but not by the user
- **precast concrete product -** concrete product cast and cured in a place other than the final location of use

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Concrete works

- mixing
- transport
- placing
- compacting
- formwork removal
- curing

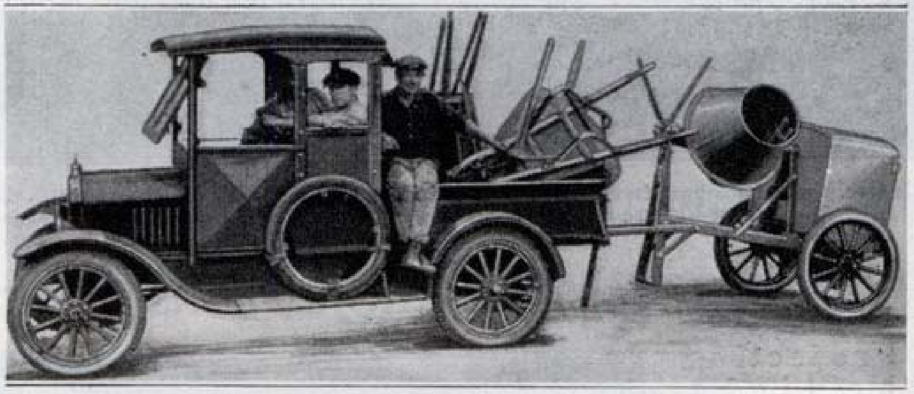




On site mixed concrete

CONCRETE MIXER HAS RUBBER-TIRED WHEELS

A new concrete mixer, now being offered for contractors' use, is mounted on a rubber-tired two-wheel truck so that it can be easily and quickly moved from one job to another. Whereas the usual portable type of mixer cannot be hauled faster than about 10 miles an hour, this one will trail behind a light auto truck at a speed of 30 miles an hour. A leg, set on the ground when the mixer is in use, supports it in a level position. It travels noiselessly and without jarring, and is no hindrance to traffic.



Concrete Mixer Mounted on a Rubber-Tired Two-Wheeled Truck, Which can be Hauled behind an Auto Truck at a 30-Mile Pace Instead of the Usual 10 Miles an Hour

On site mixed concrete

- mobile concrete batching plant

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Ready mixed concrete

- concrete plant

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Concrete transport

- transferring of concrete from the mixing plant to the construction site

Main methods:

- mortar pan, wheelbarrow
  - on-site mixed concrete
- crane bucket and ropeway
- chute
- transit mixer
- pump

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Concrete transport

Concrete consolidation

To get rid of the air voids:

- statical compacting
  - rodding, tamping, ramming
- dynamical
  - vibrating (immersion or surface vibrators)
- combined
  - pressure and jolting
- self- compacting
  - plasticizers

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Concrete consolidation

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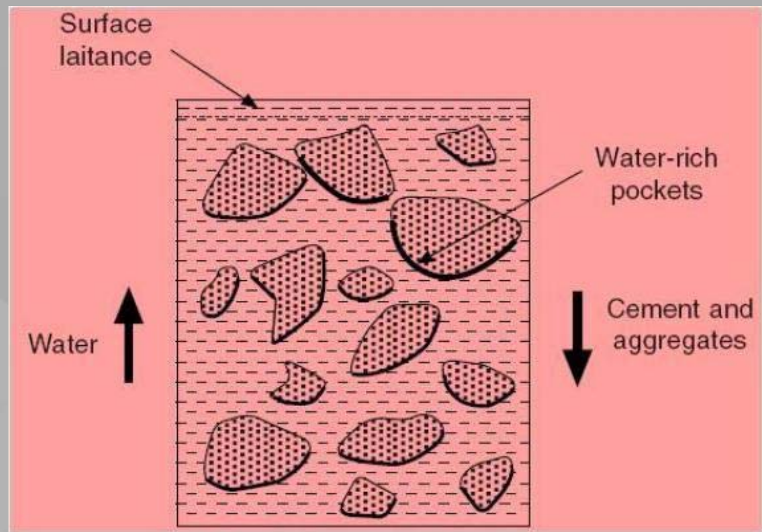
Segregation of concrete

- the separation of the constituent materials of concrete resulting in non-uniform mix (usually by over-vibration)
  - the denser aggregates settle to the bottom while the lighter cement paste tends to move upwards



Concrete curing

- any procedure that maintains proper moisture and temperature of the concrete to ensure continuous hydration
- if the water is allowed to evaporate the hydration ceases and the concrete shrinks → **cracks occur !**

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Concrete curing methods

- ponding
- wrapping in plastic or wet cloth
- spraying on temporary curing membrane

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Minimal time of curing

		Minimal time of curing in days			
Strength development	Estimate of $f_{cm,2}/f_{cm,28}$	Surface temperature υ in °C			
		$\upsilon \geq 25$	$25 > \upsilon \geq 15$	$15 > \upsilon \geq 10$	$10 > \upsilon \geq 5$ h)
rapid	$\geq 0,5$	1	1	2	3
medium	$\geq 0,3$ to $< 0,5$	2	2	4	6
slow	$\geq 0,15$ to $< 0,3$	2	4	7	10
very slow	$< 0,15$	3	5	10	15