Building materials

Lecture 8

Building materials

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Non-hydraulic binders

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

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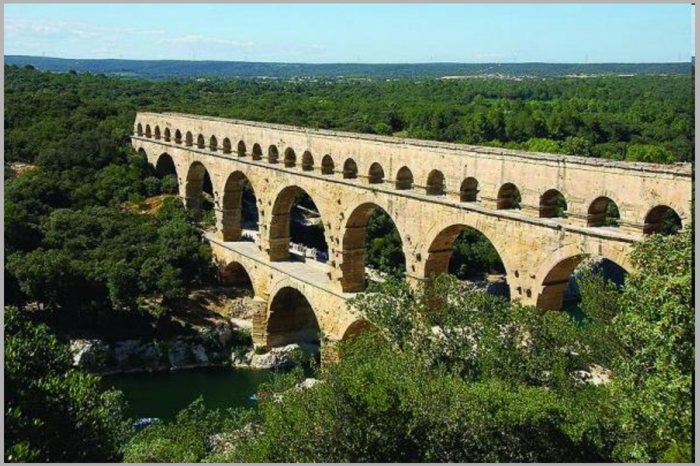
Air (non hydraulic) **lime**



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

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Building limes classification

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

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Air lime manufacturing

Raw material:

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

Air lime manufacturing

Pieter van Laer (1599 – 1642)

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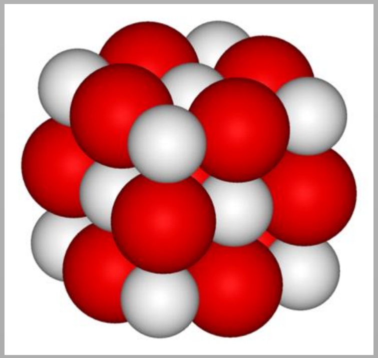
Air lime manufacturing

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



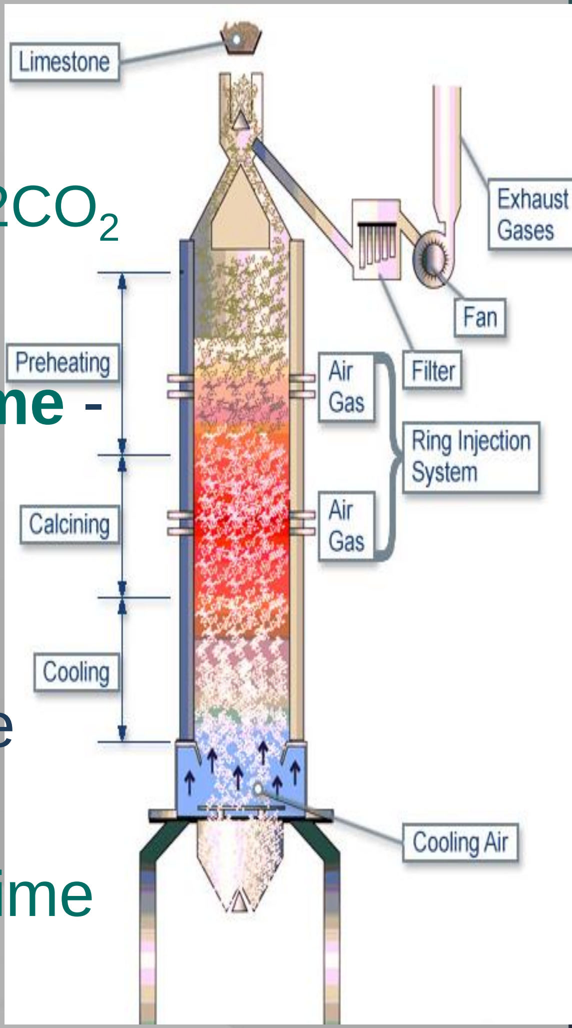
- step 2 – **slaking** (hydration)→ **hydrated lime** $\mathbf{Ca(OH)_2}$
  - lime water, slurry, putty, milk of lime
  - powder

Air lime burning

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

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

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



- 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

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:

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

- highly exothermic process

Types of hydration:

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

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!**

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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:

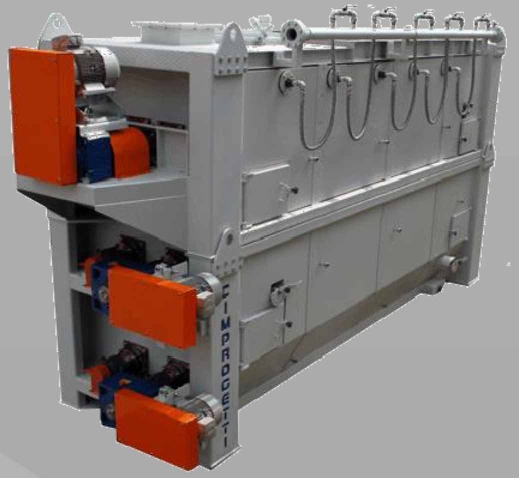
- quality of quicklime
- specific surface
- temperature (slightly under 100 °C)
- amount of water added
  - to much water → drowning (killing) the lime

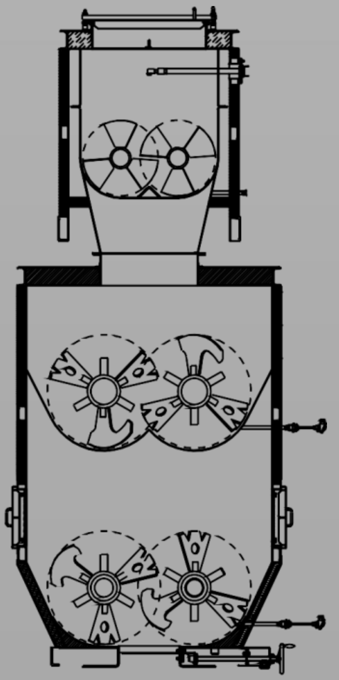
Imperfect slaking:

- **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**

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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

Lime cycle

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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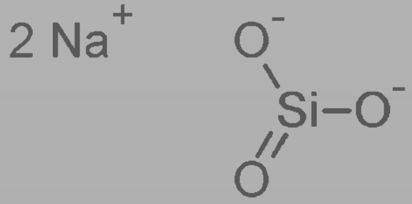
Water glass

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

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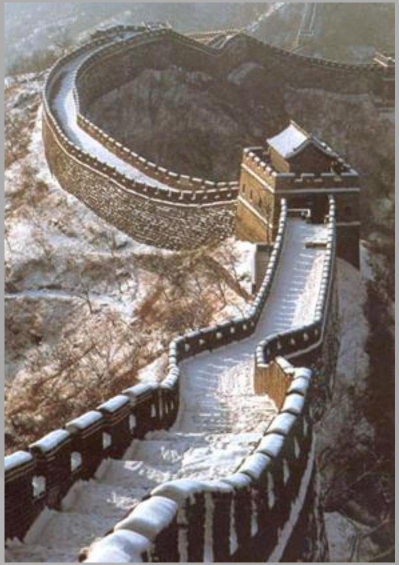
Water glass use

- **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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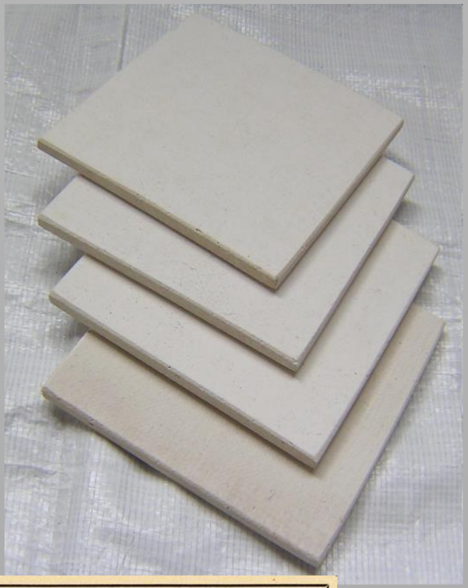
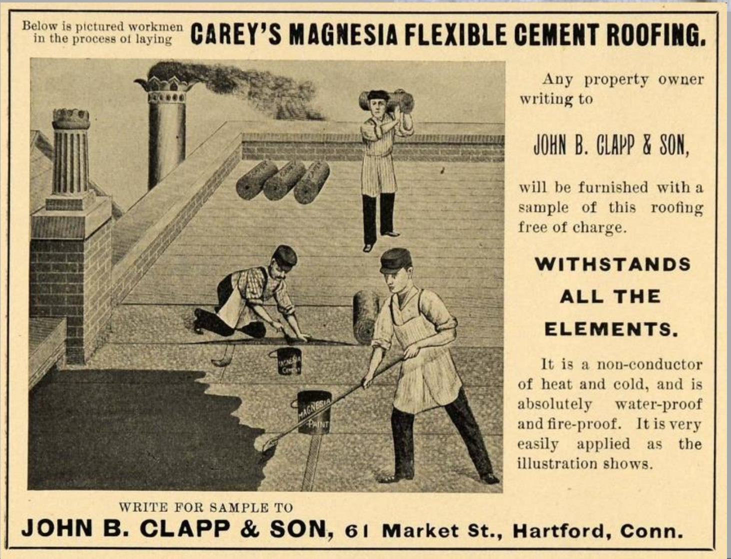
Magnesia binder use

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





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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

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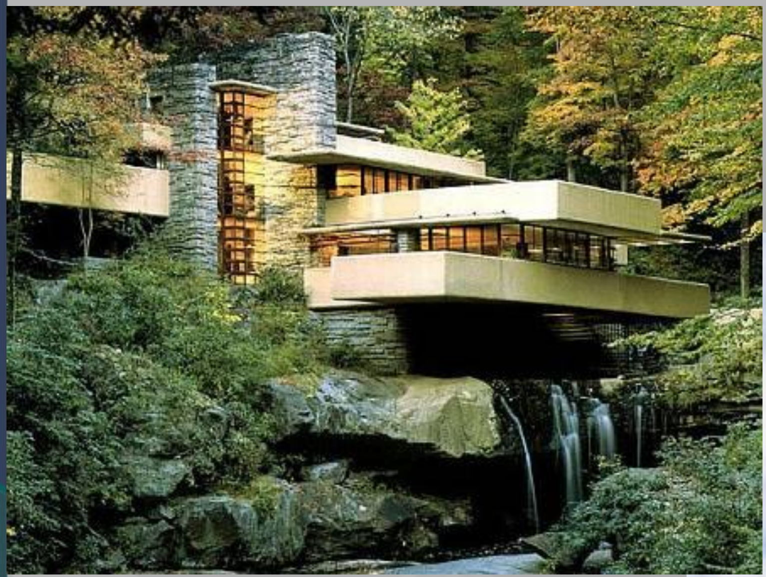
Concrete



Fallingwater, Pennsylvania

Frank Lloyd Wright, 1939

Dancing house, Prague

V. Milunić, F. Gehry, 1996

Petronas Twin Towers, Kuala Lumpur

César Antonio Pelli, 1999

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

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Concrete components

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

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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

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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

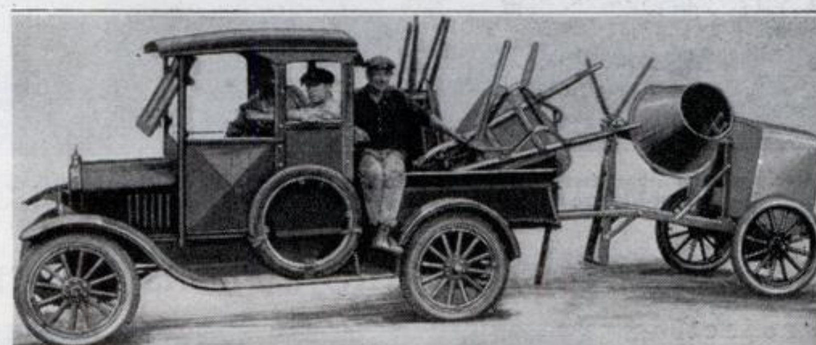




On site mixed concrete

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.



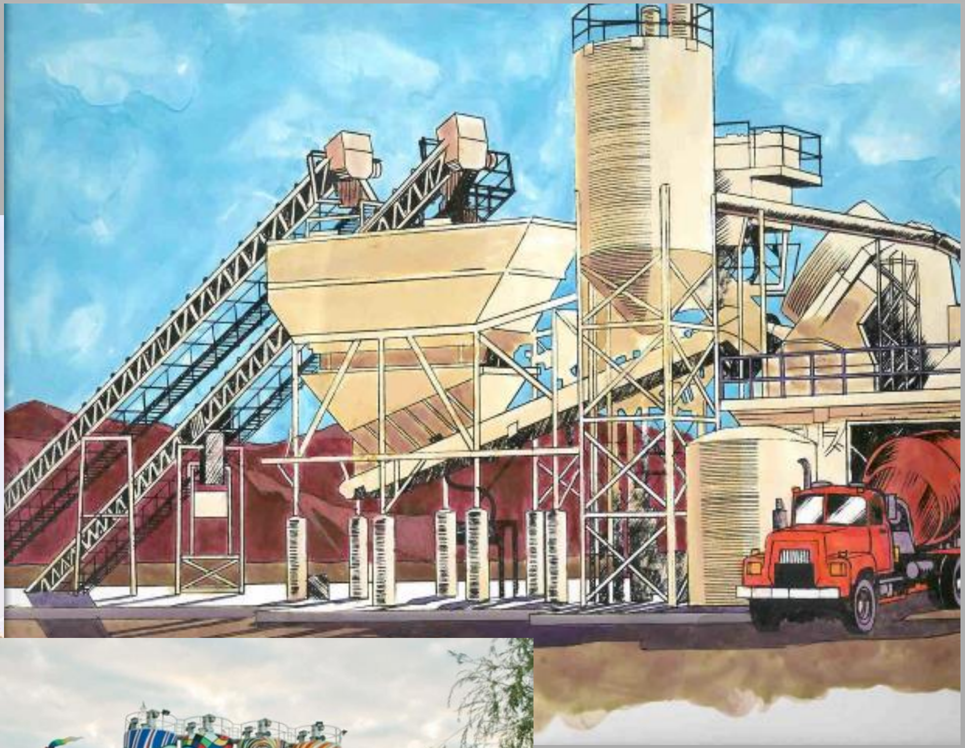
Concrete Mixer Mounted on a Rubber-Tired Two-Wheeled Truck, Which can be Hauled behind an Auto Truck at a 30-Mile Pace Instead of the Usual 10 Miles an Hour

On site mixed concrete

- mobile concrete batching plant

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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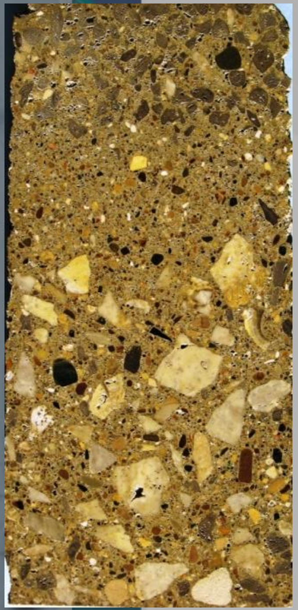
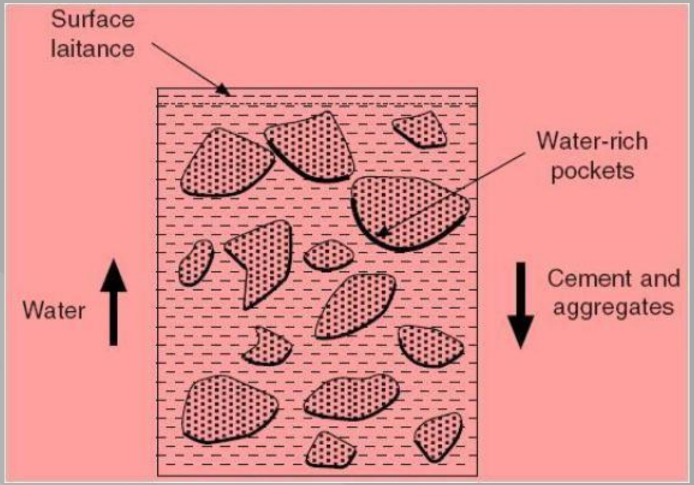
Segregation of concrete

- 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

Strength development	Estimate of $f_{cm,2}/f_{cm,28}$	Minimal time of curing in days			
		Surface temperature ϑ in °C			
		$\vartheta \geq 25$	$25 > \vartheta \geq 15$	$15 > \vartheta \geq 10$	$10 > \vartheta \geq 5$ [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

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Concrete constituents

- **binder**
- **aggregates**
- **mixing water**
- admixture
- additions
- reinforcement

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Cement

- **binder** – mixing with water → cement paste → **cement stone**
- has to conform with **EN 197-1**
- most expensive part of the concrete – as little cement as possible should be used

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Cement dosage

Minimal:

- **unreinforced concrete:** **200 kg** /1m^3 of finished concrete
- **reinforced concrete :**
  - sheltered: **240 kg**/1m^3
  - unsheltered: **260 kg**/1m^3
  - watertight constructions: **300 kg**/1m^3

Strength increases (in normal concrete) **to the amount 450 kg/1m^3**

→ **higher dosage is not economical !**

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Other binders

- **polymers** + high strength, good resistance against aggressive environment, fast setting and hardening

  - demanding production, price , fire resistance
- **asphalts** - **roads**
- **gypsum** - only in dry places
- **clays** - low strength, volume instability

Aggregates

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Aggregates

- **granular mineral material suitable for use in concrete**
- aggregates may be natural, artificial or recycled from material previously used in construction
- gravels, stone and sands form the granular structure, which must have its voids filled as completely as possible by the binder glue
- approximately **80 % of the weight and 70 – 75% of the volume of the concrete**

EN standards for aggregates

- **EN 12620** – **Aggregates for concrete**
  - normal and heavy-weight aggregates

- **EN 13055-1** - **Lightweight aggregates. Lightweight aggregates for concrete, mortar and grout**

- **EN 13043** Aggregates for bituminous mixtures and surface treatments
- **EN 13055-2** Lightweight aggregates for bituminous mixtures and surface treatments

Standard and special aggregates

Standard aggregates	Bulk density 2.2–3 kg/dm³	From natural deposits, e.g. river gravel, moraine gravel etc. Material rounded or crushed (e.g. excavated tunnel)
Heavyweight aggregates	Bulk density > 3.0 kg/dm³	Such as barytes, iron ore, steel granulate. For the production of heavy concrete (e.g. radiation shielding concrete)
Lightweight aggregates	Bulk density < 2.0 kg/dm³	Such as expanded clay, pumice, polystyrene. For lightweight concrete, insulating concretes
Hard aggregates	Bulk density > 2.0 kg/dm³	Such as quartz, carborundum; e.g. for the production of granolithic concrete surfacing
Recycled granulates	Bulk density approx. 2.4 kg/dm³	From crushed old concrete etc.

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Origin of aggregates

- **natural aggregate -** aggregate from mineral sources which has been subjected to nothing more than mechanical processing
- **manufactured aggregate -** aggregate of mineral origin resulting from an industrial process involving thermal or other modification
- **recycled aggregate -** aggregate resulting from the processing of inorganic material
- **recovered aggregate -** aggregate recovered from wash water or fresh concrete

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Properties of aggregates

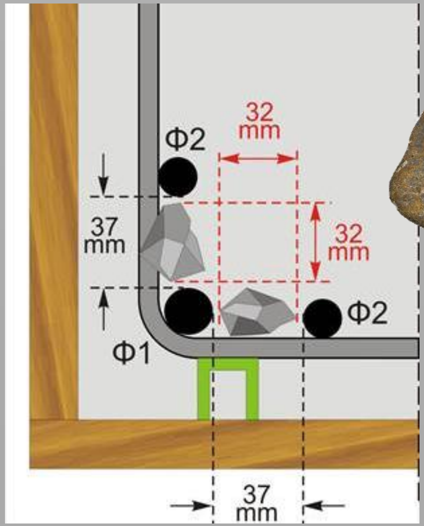
Required for mix design:

- **grading**
- **durability**
- **particle shape** and surface texture
  - rounded, smooth aggregates - more workable mix
  - angular, rough aggregates - harder to place, work and compact concrete, but concrete is stronger
- **abrasion** and skid resistance
- **unit weights** and voids
- **absorption** and **surface moisture**

Maximum aggregate size D_{max}

D_{max} shall be selected taking into account the cover to reinforcement and the minimum section width

- **max. 1/3 to 1/2 of the narrowest dimension** of a concrete member
  - columns - max.1/4
  - horizontal slabs - max.1/2
- **1/3 of diameter of pump hose**
- max. **1,3 times of bar cover**
- **spacing between bars – 5 mm**
- **use of the largest possible maximum size** (with some limitations)



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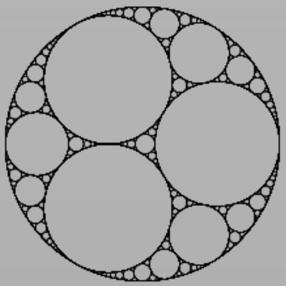
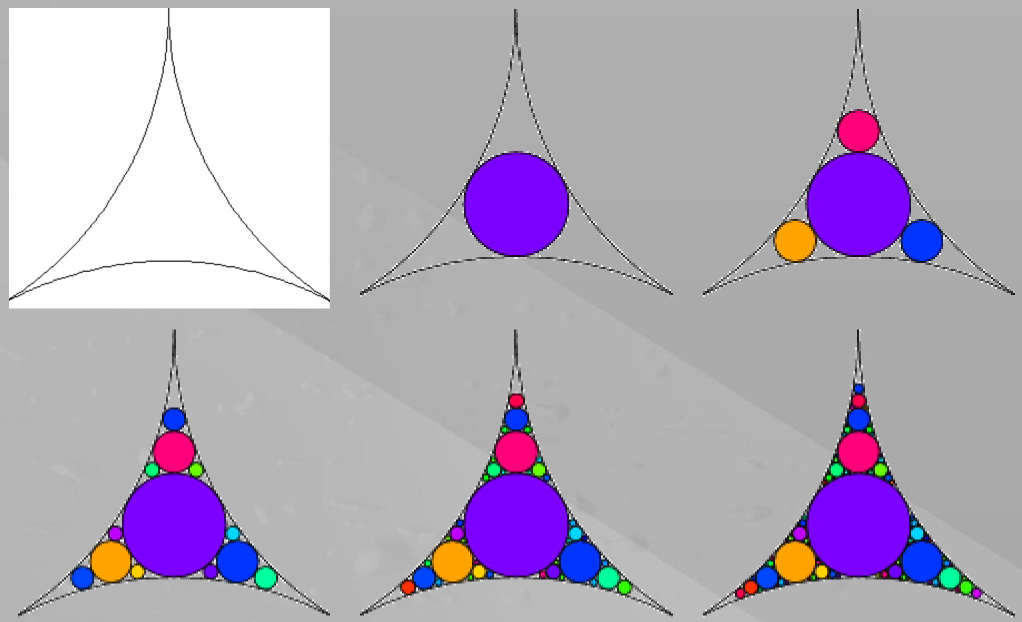
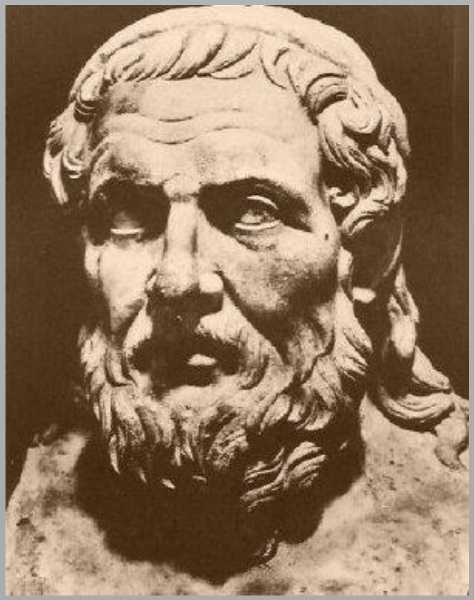
Gradation

- ideal filling of space
  - less voids in concrete





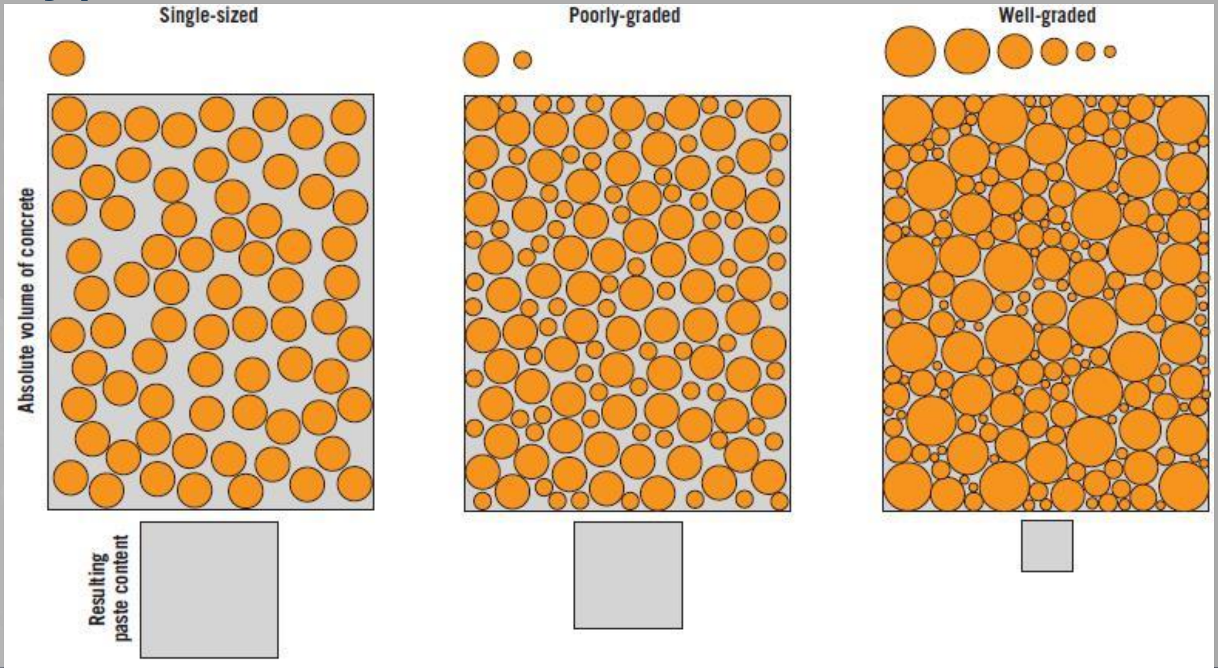


Apollonius from Perga
(262-190 BC)

Aggregates gradation

Particle-size distribution has an impact on:

- **bulk density and strength** of concrete
- **workability** (consolidation, finishability, and pumpability)
- **cost**



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Ideal gradation

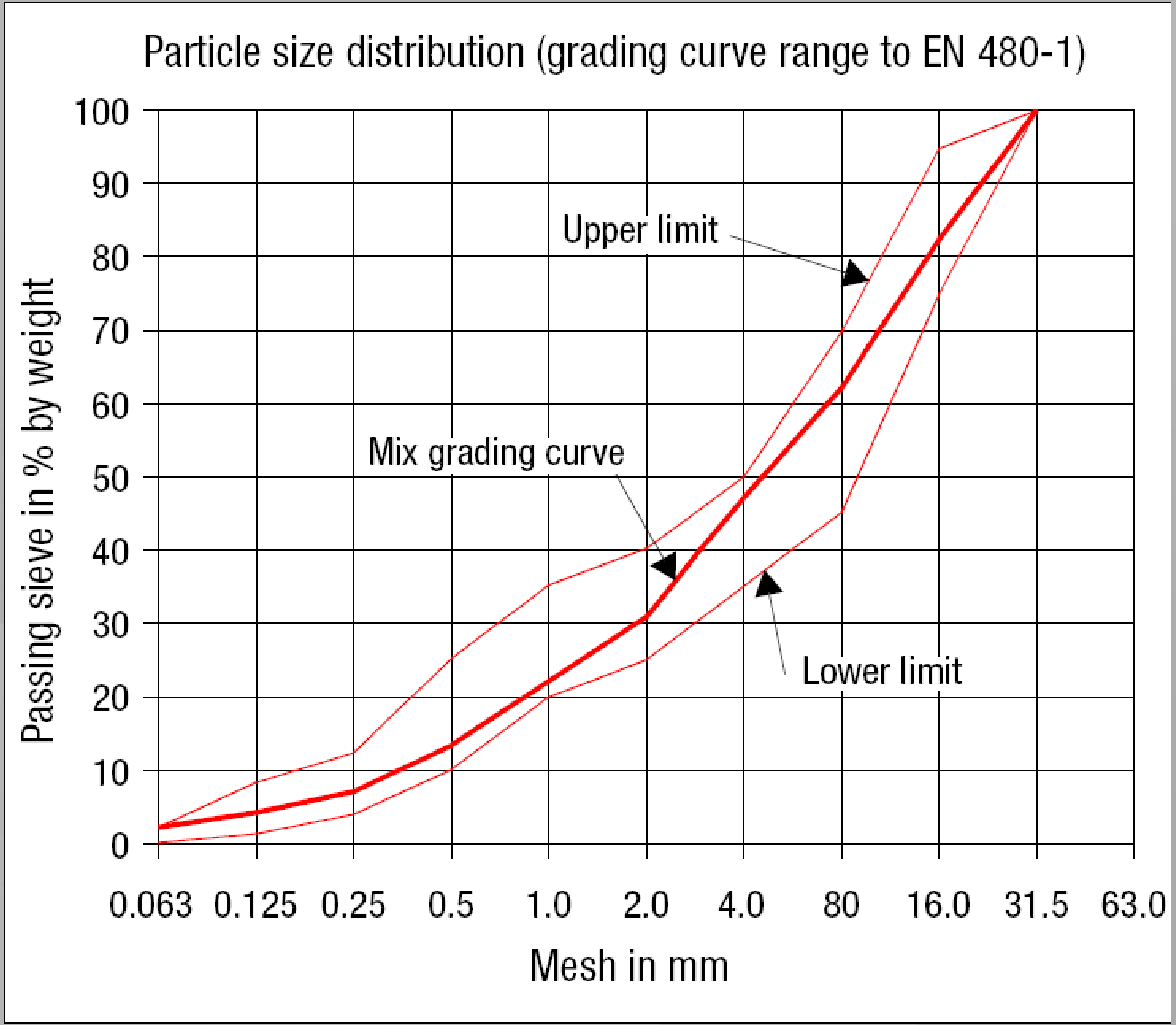
- **Fuller equation**

$$y_i = 100\sqrt{\frac{d_i}{D_{max}}}$$

  - Bolomey, EMPA, Kenedy, Hummel, Valete

- **two fractions minimally, better three**

F : C = 1: (1,5 – 2)



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Physical properties (EN 12620)

- **resistance to fragmentation of coarse aggregate**
  - **Los Angeles coefficient**
  - **resistance to impact**

- **resistance to wear** - micro-Deval
- **resistance to polishing and abrasion**
- **particle density and water absorption**
- **bulk density**
- **durability**
  - **freeze/thaw resistance**
  - **volume stability - drying shrinkage**
  - **alkali-silica reactivity**

Freeze/thaw resistance

Freeze-thaw Percentage loss of mass [a]	**Category** *F*
≤ 1 ≤ 2 ≤ 4 > 4	F_1 F_2 F_4 $F_{Declared}$
No requirement	F_{NR}

Environmental conditions	**Climate**		
	Mediterranean	**Atlantic**	**Continental** [a]
Frost free or dry situation	Not required	Not required	Not required
Partial saturation, no salt	Not required	F_4 or MS_{35}	F_2 or MS_{25}
Saturated, no salt	Not required	F_2 or MS_{25}	F_1 or MS_{18}
Salt (seawater or road surfaces)	F_4 or MS_{35}	F_2 or MS_{25}	F_1 or MS_{18}
Airfield surfacings	F_2 or MS_{25}	F_1 or MS_{18}	F_1 or MS_{18}

[a] The Continental category could also apply to Iceland, parts of Scandinavia and to mountainous regions where severe winter weather conditions are experienced.

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Chemical properties (EN 12620)

- **chlorides**
- **sulfur containing compounds**
  - **acid-soluble sulfate**
  - **total sulfur**
- **other constituents**
  - **constituents which alter the rate of setting and hardening of concrete – organic substances**
  - **constituents which affect the volume stability of air-cooled blastfurnace slag**
- carbonate content of fine aggregates for concrete pavement surface courses

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Chlorides in aggregates

- chlorides may dissolve in the mixing water and promote corrosion of steel
- **maximum chloride content is** expressed as percentage of water-soluble chloride ion content by mass of combined aggregate
  - plain concrete – 0,15 %
  - reinforced concrete – 0,06 %
  - prestressed concrete – 0,03 %

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Sulfur content in aggregates

- **total sulfur content** - expressed as percentage by mass of the aggregate
  - max. 1% (2 % for blastfurnace slag)

- **sulfides** (FeS_2, PbS) - source of sulfates
- **sulfates** ($CaSO_4$, $PbSO_4$) - sulfate corrosion

Aggregate	**Acid soluble sulfate content** Percentage by mass	**Category** *AS*
Aggregates other than air-cooled blastfurnace slag	≤ 0,2 ≤ 0,8 > 0,8	$AS_{0,2}$ $AS_{0,8}$ $AS_{Declared}$
	No requirement	AS_{NR}
Air-cooled blastfurnace slag	≤ 1,0 > 1,0	$AS_{1,0}$ $AS_{Declared}$
	No requirement	AS_{NR}

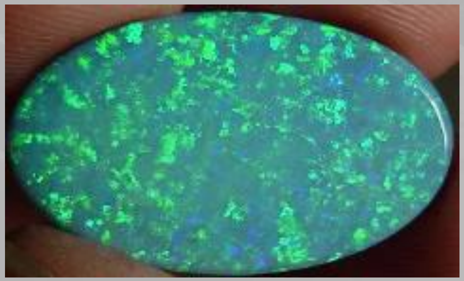
Organic impurities in aggregates

- **humus content** (decaying vegetation), **fulvo acids** (humic acids)
  - retarding effect on cement
  - colorimetric tests (NaOH, KOH)
  - **comparison with standard color**

- **sugars -** influence on setting and hardening – decrease of strength
- **carbonate content**
  - lignite and coal particles may cause brown stains and/or popouts to appear at the surface

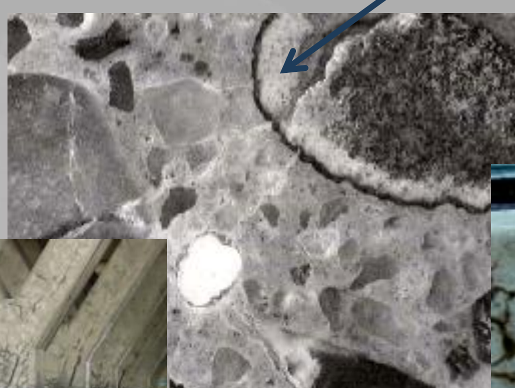
Alkali - silica reaction

- certain aggregates can react with alkaline hydroxides present in the pore fluids of concrete
- under adverse conditions and in the presence of moisture this can lead to expansion and subsequent cracking or disruption of the concrete - ASR
- less common is alkali-carbonate reaction



Alkali-silica reaction - ASR

- occurs over time in concrete between the highly alkaline cement paste and reactive non-crystalline (amorphous) silica
- formation of a swelling gel of calcium silicate hydrate (CSH gel)



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Water

Water

- **mixing water**
  - **hydration**
  - **workability**

- **curing water**

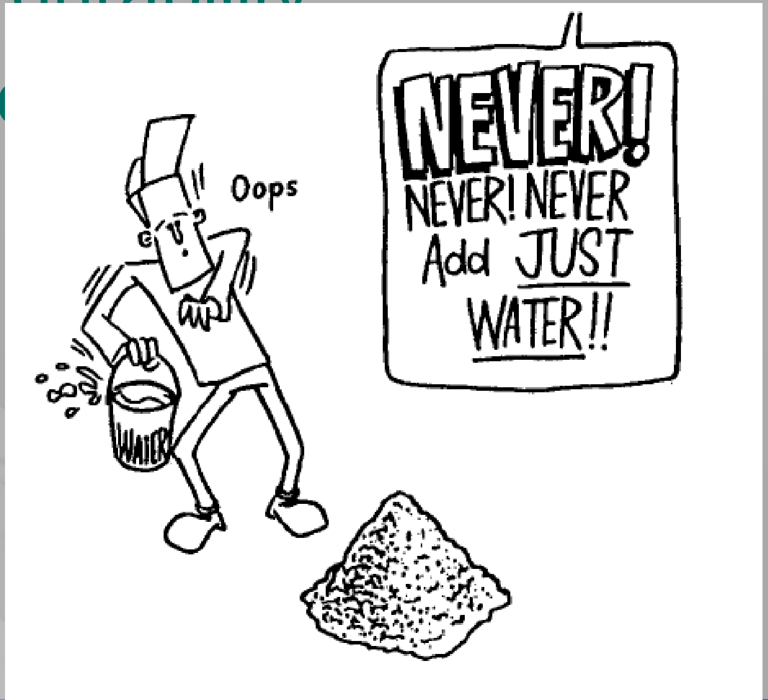
Mixing water - EN 1008

- **potable water**
  - suitable for use in concrete without testing
- **water recovered from processes in the concrete industry**
  - normally suitable for use in concrete, but shall conform to the requirements of standard
- **water from underground sources**
- **natural surface water and industrial waste water**
  - both suitable for use in concrete, but shall be tested
- **sea water or brackish water**
  - may be used for concrete without reinforcement or other embedded metal
  - not suitable for the production of reinforced or prestressed concrete
- **sewage water**
  - not suitable for use in concrete

Water - cement ratio

- in standard concrete: **w/c = 0,35 - 0,8**
- minimum for hydration **0,23 l**/1 kg of cement
- low w/c ratio
  - higher strength and durability
  - the mix difficult to w

→ more water is used than it is necessary for reaction with cement



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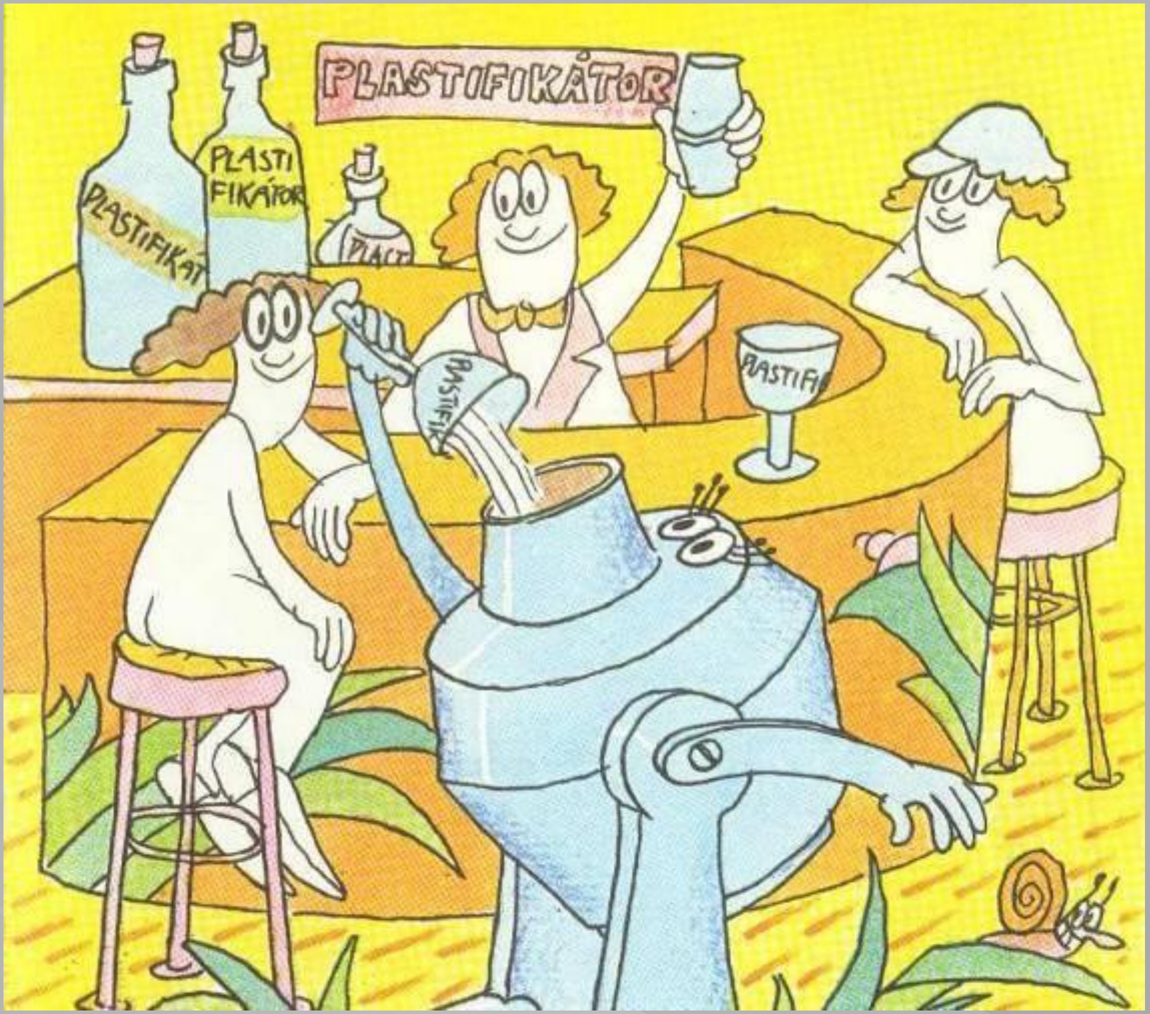
Admixtures



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Admixtures

EN 934-2:

- material added during the mixing process of concrete **in small quantities** related to the mass of cement (0,2 – 5 %) to modify the properties of fresh or hardened concrete
- mostly liquid

Admixture types (EN 934-2)

- water reducing/plasticizing
- high-range water reducing/superplasticizing
- water retaining
- water resisting
- air entraining
- set accelerating
- hardening accelerating
- set retarding
- dual function admixtures
  - set retarding/water reducing/plasticizing
  - set retarding/high-range water reducing/superplasticizing
  - set accelerating/water reducing/plasticizing

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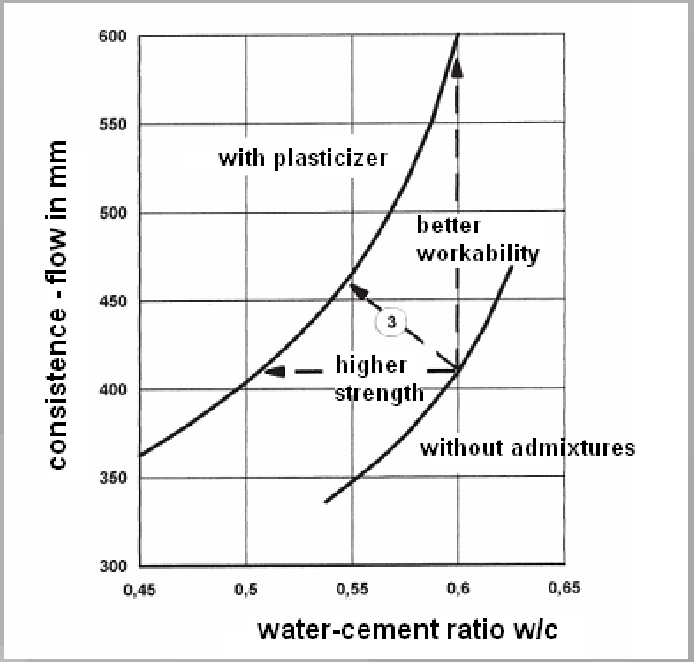
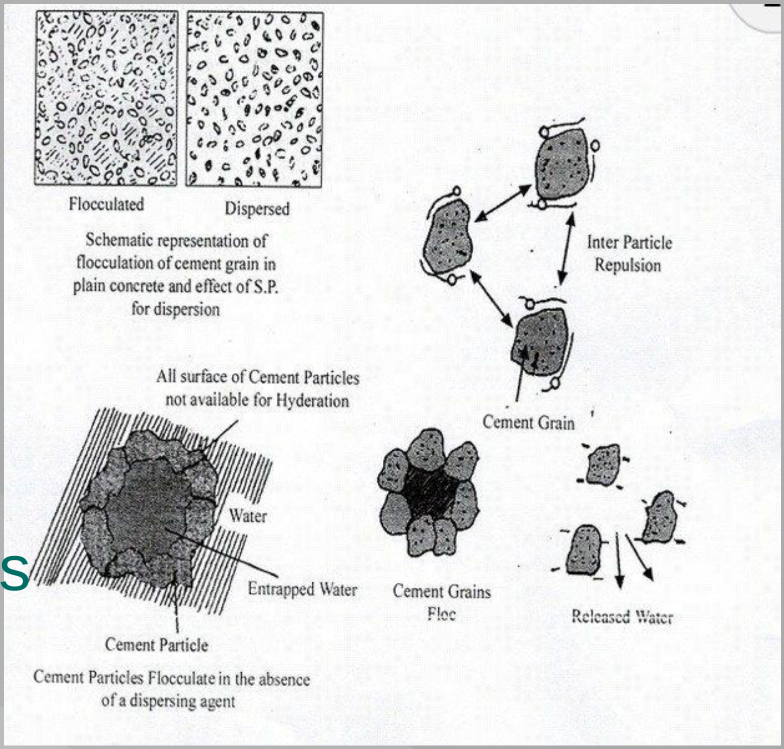
Plasticizing and superlasticizing admixtures

- Enables the water content of a given concrete mix to be reduced without affecting the consistence, or increases the workability without changing the water content, or achieves both effects
  - reduction ⟨5% -12%) *(plasticizer)*
  - reduction ≥ 12% *(superplasticizer)*



Plasticizing/Water reducing admixtures

- admixture is adsorbed on to the cement particles and lowers the inter particular attraction so that flocs of cement break up



  - lignosulphonate
  - hydrocarbolic acids salts
  - carbohydrates

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Superplasticizers

- **increased fluidity**
  - flowing, self-leveling, self-compacting concrete
  - penetration and compaction round dense reinforcement
- **reduced W/C ratio:**
  - very high early streng
  - very high later age str
  - reduced shrinkage (es reduced cement conte
  - improved durability by permeability and diffu

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Superplasticizers

- **Sulphonated melamine formaldehyde condensates (SMF)**
  - 16–25% water reduction, little or no retardation $\rightarrow$ very effective at low temperatures
- **Sulphonated naphthalene formaldehyde condensates (SNF)**
  - 16–25% water reduction.
  - tend to increase the entrapment of larger, unstable air bubbles
- **Polycarboxylate ether superplasticizers (PCE)**
  - 20–35%+ water reduction
  - relatively expensive

Air-entraining admixtures

- introduces a specific quantity of small, evenly distributed air voids during the mixing process which remain in the concrete after it hardens
  - < 0.5 mm, typically 0.01 – 0.02 mm
  - surfactants - natural wood resins,animal and vegetable fats and oils, water soluble soaps
  - for every 1% of additional air entrained the concrete strength fall by 5 to 6%
- increase **durability against freeze/thaw** effect
- increase cohesion in the mix, reducing bleed water and segregation of the aggregate

Retarding admixtures

- **slow the rate of cement hydration, preventing the cement from setting before it can be placed and compacted**
- increase in initial (≥ 90 min) and final setting times (≤ 360 min)
- **mainly used in hot conditions and climates**
- sucrose and other polysaccharides, citric acid, tartaric acid, salts of boric acid, salts of phosphoric, poly-phosphoric and phosphonic acid

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Accelerating admixtures

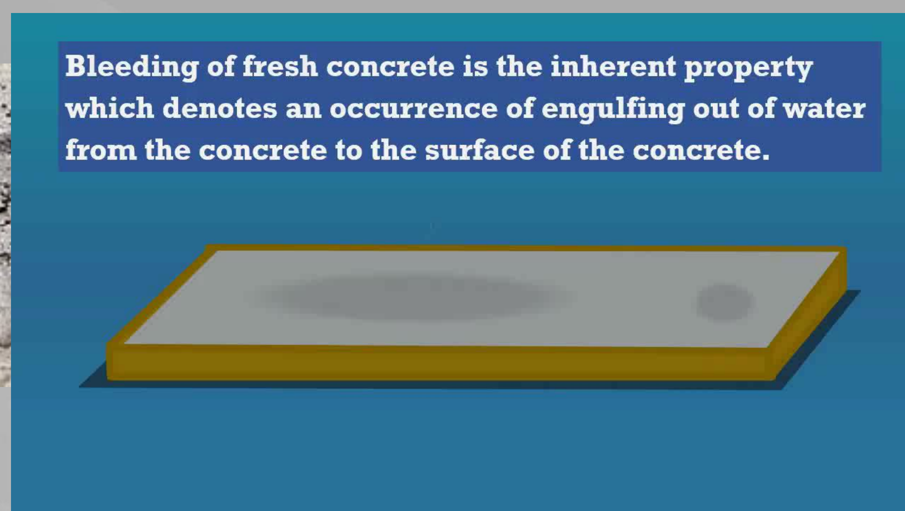
- **set accelerators** - reduces the time to initial set, with an increase in initial strength
- **hardening accelerators** - accelerate the initial strength with or without an effect on the setting time.

Used

- in cold conditions
- where early stripping of shuttering or very early access to pavements is required

Stabilizing admixtures

- **against bleeding**
- bleeding:
  - emergence of water on the surface caused by separation of the concrete
  - often a result of defects in fines in the aggregate and in low cement or high water containing mixes



Other admixtures

- corrosion inhibiting
- shrinkage reducing
- water resisting - to prevent absorption
- gas formers, foamers – lightweight concrete
- fungicidal
- anti-washout / underwater admixtures
- pumping aids
- bonding

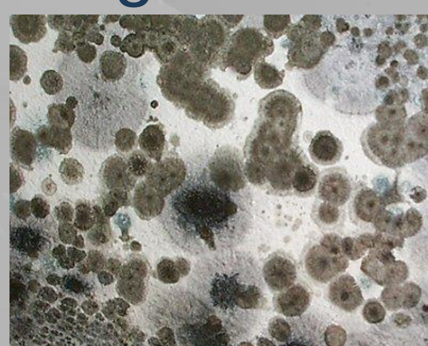


Fig. 6-1. Liquid admixtures, from left to right: antiwashout admixture, shrinkage reducer, water reducer, foaming agent, corrosion inhibitor, and air-entraining admixture. (69795)

Admixtures

- if more than one admixture is added, their compatibility must be verified by specific testing
- if the total quantity of liquid admixture is > 3 l/m³ of concrete, the water quantity must be included in the w/c calculation
- permitted dosage - ≤ 5% by weight of the cement (the effect of a higher dosage on the performance and durability of the concrete must be verified)
- low dosages < 0.2 % are only allowed if they are dissolved in part of the mixing water

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Additions

- finely divided material used in concrete in order to improve certain properties or to achieve special properties
  - nearly inert additions (type I)
  - pozzolanic or latent hydraulic additions (type II)
- added to concrete in significant proportions (around 5–20 %)
- type II additions may be taken into account in the concrete composition

Additions

Type I - nearly inert additions

- pigments, rock flours (quartz dust, powdered limestone)
- improving of the grading curve, stability and fluidity

Type II - pozzolanic materials

- natural pozzolans, fly ash, silica fume, blast furnace slag, calcined clay, rice husk ash
- replacing part of cement, improving pumpability, enhancing early strength development and durability, resistance to abrasion, impact and chemical attack

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Concrete degradation

In aggressive environment:

- **decalcification**
- **leaching**
- **sulfate attack**
- **chlorides**
- **bacterial corrosion**
- **seawater**

- **carbonation** – steel corrosion

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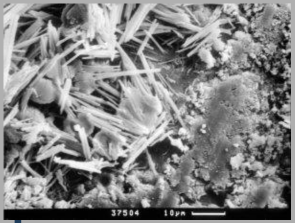
Concrete degradation

- **decalcification**
  - distilled water (e.g. from condensed steam) can wash out calcium content in concrete, leaving the concrete in brittle condition
- **leaching**
  - flowing water may dissolve various minerals present in the hardened cement paste or in the aggregates
- **chlorides**
  - calcium chloride and (to a lesser extent) sodium chloride leach calcium hydroxide and cause chemical changes in Portland cement, leading to loss of strength

Sulphate attack

- **external**
  - penetration of sulfates in solution into the concrete from outside
- **internal**
  - a soluble source incorporated into the concrete at the time of mixing



- the soluble sulphate salts react with C_3A in concrete → **ettringite** is formed

$$3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot \mathbf{31H_2O}$$

- the volume of the resulting ettringite is greater than the volume of the original substances → internal pressures which fracture the concrete → **loss of concrete strength**

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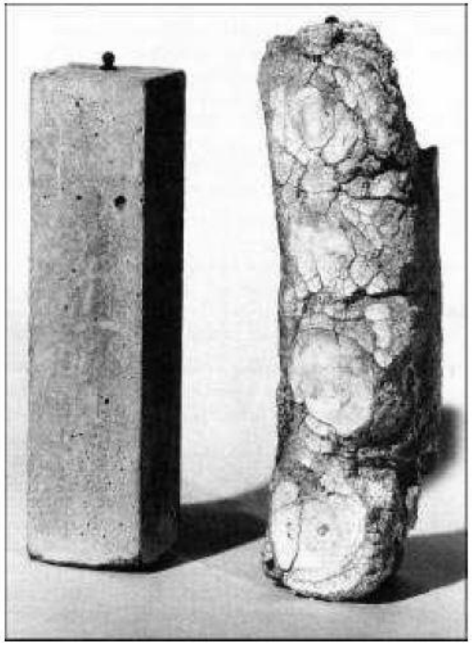
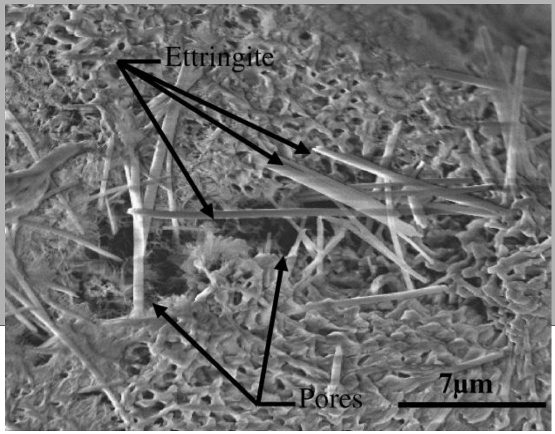
Sulphate attack



4.1 Conventional sulfate attack associated with expansive ettringite formation in a concrete prism (RHS) and non-degraded control prism (LHS). Photograph reproduced from CEB Design Guide, *Durable Concrete Structures*, London, Thomas Telford, 1989.



Relative strength [%]

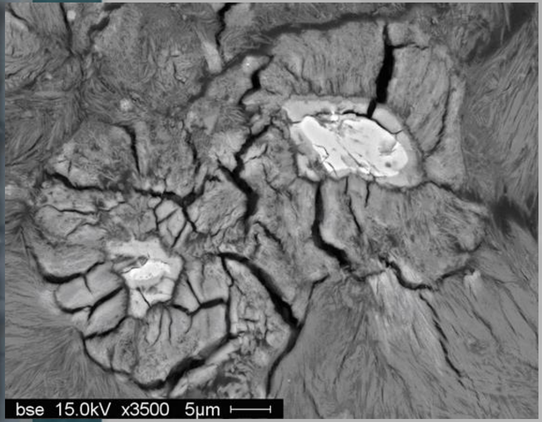
sulphate resistant cement (C_3A< 3,5 %)

cement with C_3A< 8 %

portland cement (C_3A ~ 12 %)

Time of exposition in sulphate solution [days]

Sulphate attack



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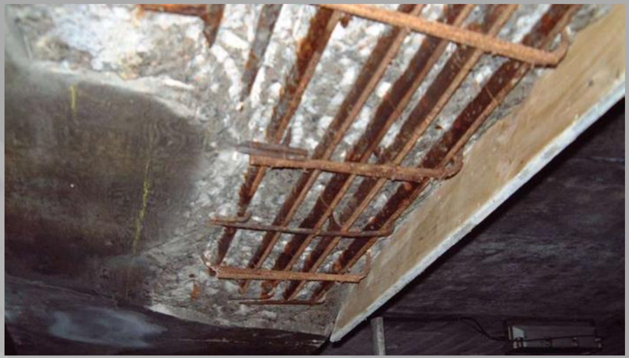
Concrete carbonation

– a chemical reaction between carbon dioxide in the air with calcium hydroxide and hydrated calcium silicate in the concrete - needs moisture

→ decrease of alkalinity under pH = 10

→ **corrosion of steel reinforcement**



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Concrete carbonation

- atmospheric **CO_2** can penetrate concrete and react with **$Ca(OH)_2$** in the cement paste to form **$CaCO_3$** and this reaction **reduces the pH** of the concrete to around 9

$$\mathbf{Ca(OH)_2 + CO_2 \xrightarrow{(H_2O)} CaCO_3 + H_2O}$$

  - water is required for the reaction to proceed
  - if the pores of the concrete are filled with water, the diffusion of CO_2 is slowed

→ carbonation does not occur in dry environment and under water

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Corrosion of steel reinforcement

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Corrosion of steel reinforcement

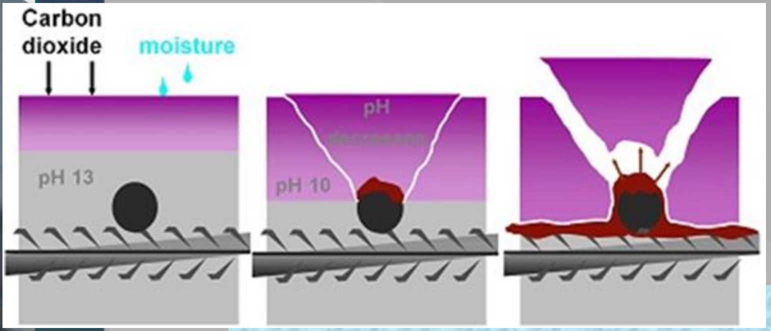
- **fresh concrete is highly alkaline (pH > 12)** (presence of the hydroxides of sodium, potassium and calcium produced during the hydration reactions)
- in alkaline environment steel is **passivated** (covered by a stable protective oxide film) → **no corrosion** of the reinforcement can occur

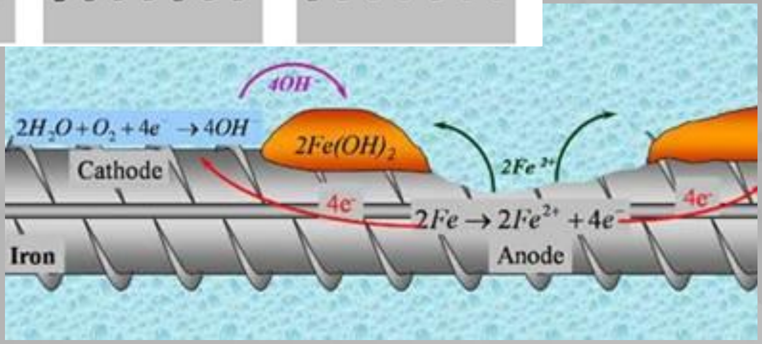
Corrosion of steel reinforcement

- when pH of concrete decreases under **9,5** (by carbonation) corrosion starts

$$2Fe+1{,}5O_2+H_2O \;=\; 2FeO(OH)$$

2,5 x higher volume than Fe





Speed of carbonation process

- c. occurs progressively from the outside surface of the concrete exposed to atmospheric CO_2, but does so at a decreasing rate because the CO_2 has to diffuse through the pore system, including the already carbonated surface zone of concrete
- **depth of carbonation**: $$D = K.\sqrt{t}$$

K… the carbonation coefficient (depends on the quality of the concrete, concentration of CO_2 and its diffusivity through the concrete)

t … exposure time

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Depth of carbonation

- test by **spraying a color pH indicator** (phenolphthalein) **on a cross section of concrete** (at pH > 9,8 purple)
- after 1 year depth ca 4 - 8 mm
- after 60-70 years - 30 - 60 mm