Building Materials

Lecture 9

Building materials

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Concrete

Continuation

Concrete degradation

In aggressive environment:

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

- **carbonation** – steel corrosion

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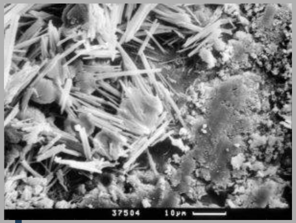
Concrete degradation

- **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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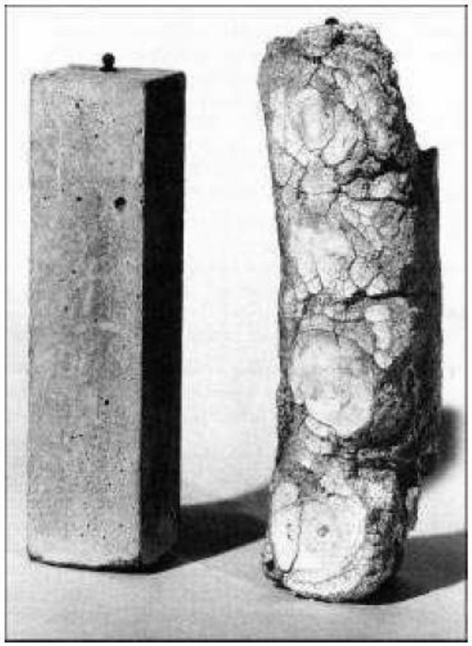
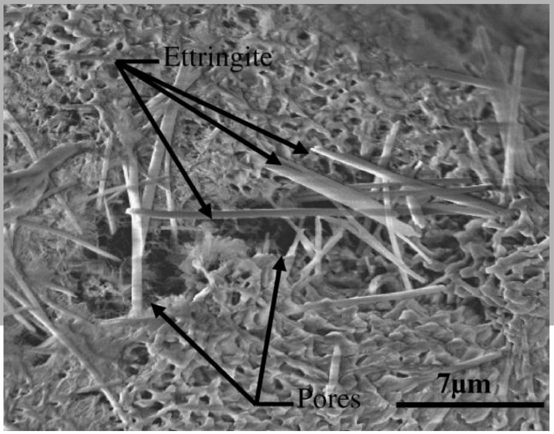
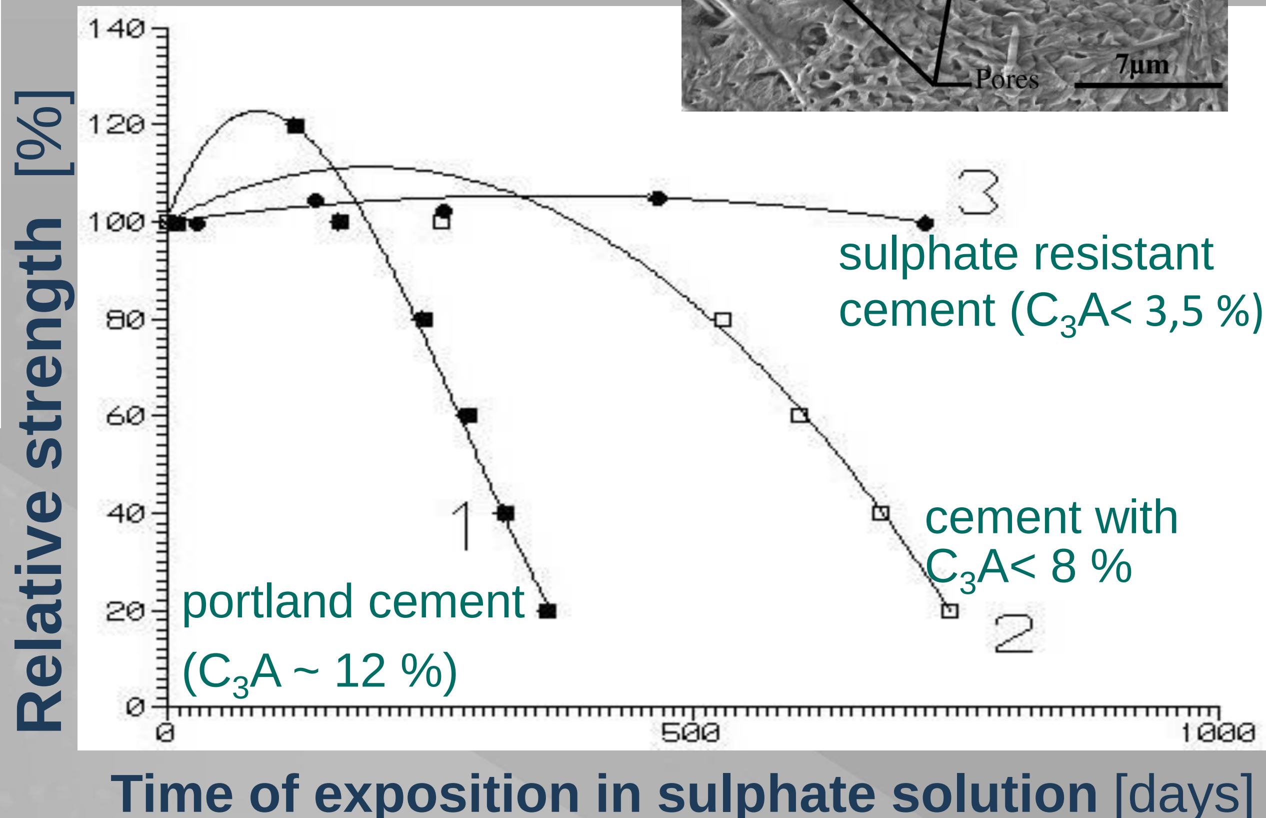
Sulphate attack

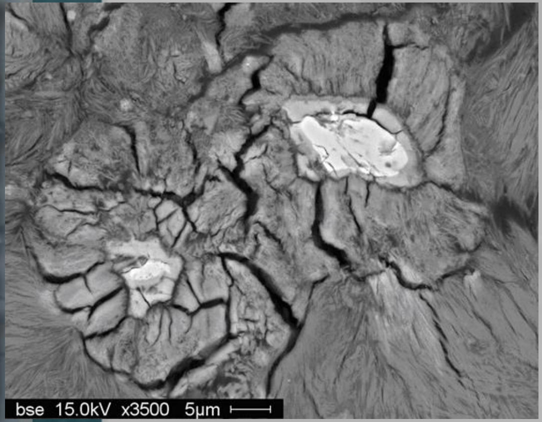


4.1 Conventional sulfate attack associated with expansive ettringite formation in a concrete prism (RHS) and non-degraded control prism (LHS). Photograph reproduced from CEB Design Guide, *Durable Concrete Structures*, London, Thomas Telford, 1989.





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

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

  - 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

Corrosion of steel reinforcement

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Corrosion of steel reinforcement

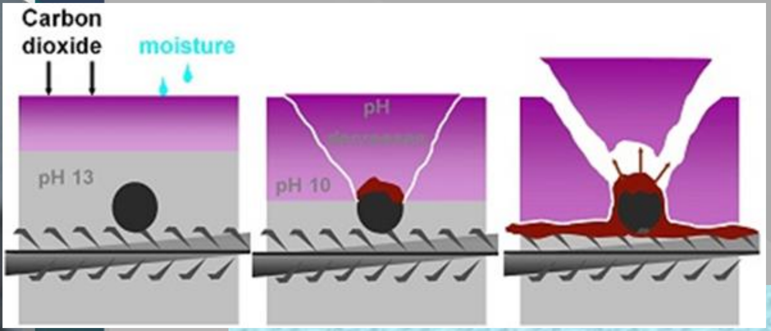
- **fresh concrete is highly alkaline (pH > 12)** (presence of the hydroxides of sodium, potassium and calcium produced during the hydration reactions)
- in alkaline environment steel is **passivated** (covered by a stable protective oxide film) $\rightarrow$ **no corrosion** of the reinforcement can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

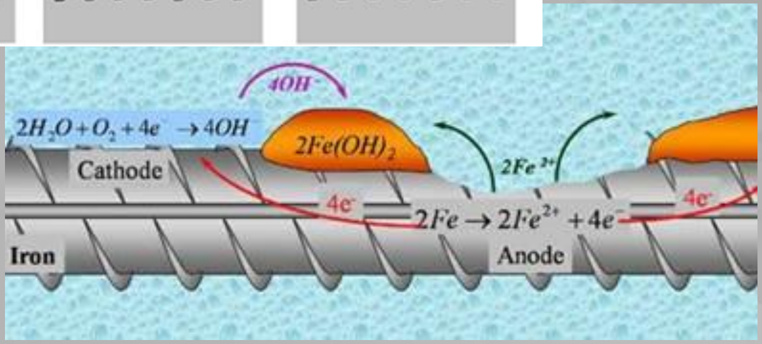
Corrosion of steel reinforcement

- 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





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Speed of carbonation process

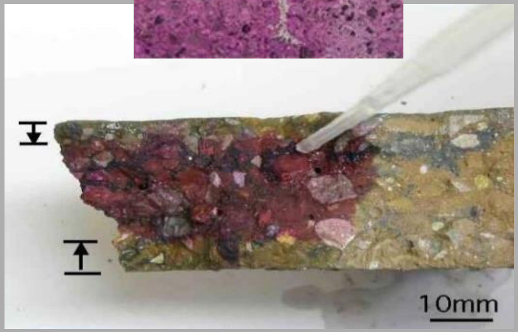
- c. occurs progressively from the outside surface of the concrete exposed to atmospheric CO_2, but does so at a decreasing rate because the CO_2 has to diffuse through the pore system, including the already carbonated surface zone of concrete
- **depth of carbonation**: $D = K.\sqrt{t}$

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

t … exposure time

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



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Specification of concrete

- technical requirements given to the producer in terms of performance or composition by **specifier** (= person or body establishing the specification) for the fresh and hardened concrete
- the specifier of the concrete shall ensure that all the relevant requirements for concrete properties are included in the specification given to the producer

Example of concrete specification

C 30/37 - XC4 - Cl0,20 - D_{max}32 - C3

Example: Pumped concrete for ground slab in ground water area

Specification conforming to EN 206-1 (designed concrete)

Concrete conforming to EN 206-1

- C 30/37 → compressive strength class
- XC 4 → exposure class
- Cl 0.20 → chloride content class
- Dmax 32 (max. particle ∅) → maximum nominal upper aggregate size
- C3 (degree of compactability) → consistence class

Pumpable

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Compressive strength class

C 30/37 - XC4 - Cl0,20 - D_{max}32 - C3

C 30/37

- **$f_{ck,cyl}$** - minimum characterictic **compressive cylinder strength**
- at 28 days
- **cylinders ø 150 mm, height 300 mm**

- **$f_{ck,cub}$** - minimum characterictic **compressive cube strength**
- at 28 days
- **150 mm cubes**

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Compressive strength classes

Compressive strength class	$f_{ck, cyl}$ (cylinder) N/mm²	$f_{ck, cube}$ (cube) N/mm²
C 8/10	8	10
C 12/15	12	15
C 16/20	16	20
C 20/25	20	25
C 25/30	25	30
C 30/37	30	37
C 35/45	35	45
C 40/50	40	50
C 45/55	45	55
C 50/60	50	60
C 55/67	55	67
C 60/75	60	75
C 70/85	70	85
C 80/95	80	95
C 90/105	90	105
C 100/115	100	115

high strength concretes

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Exposure classes

C 30/37 **- XC4 -** Cl0,20 - D_{max}32 - C3

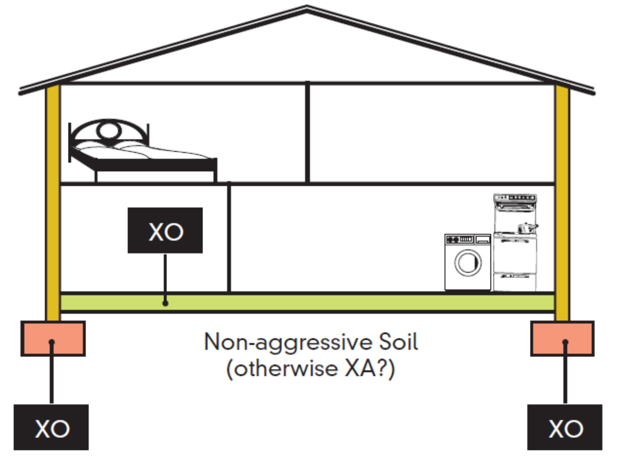
- related to environmental actions

Exposure classes

CLASS DESIGNATION:	DESCRIPTION OF THE ENVIRONMENT:	No. of sub-classes
XO	No risk of corrosion (inside buildings with very low air humidity)	1
XC	Corrosion of the reinforcement induced by carbonation	4
XD	Corrosion of the reinforcement induced by chlorides other than from sea water	3
XS	Corrosion of the reinforcement induced by chlorides from sea water	3
XF	Freeze-thaw attack with or without de-icing agents	4
XA	Chemical attack	3

X0 - no risk of corrosion or attack

Class designation	Description of the environment	Informative examples where exposure classes may occur
	No risk of corrosion or attack	
X 0	For concrete without reinforcement or embedded metal: all exposures, except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with low air humidity



Exposure classes - carbonation XC

Class designation	Description of the environment	Informative examples where exposure classes may occur
	Corrosion induced by carbonation	
X C 1	Dry or permanently wet	Concrete inside buildings with low air humidity. Concrete permanently submerged in water
X C 2	Wet, rarely dry	Concrete surfaces subject to long-term water contact; many foundations
X C 3	Moderate humidity	Concrete inside buildings with moderate or high air humidity; external concrete sheltered from rain
X C 4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure Class X C 2

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Exposure classes - freeze/thaw attack XF

- cyclic freezing and thawing of unbound water in concrete

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Exposure classes - freeze/thaw attack XF

Class designation	Description of the environment	Informative examples where exposure classes may occur
	Freeze/thaw attack with or without de-icing agents	
X F 1	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
X F 2	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
X F 3	High water saturation, without de-icing agent	Horizontal concrete surfaces exposed to rain and freezing
X F 4	High water saturation, with de-icing agent	Road and bridge decks exposed to de-icing agents; concrete surfaces exposed to direct spray containing de-icing agents and freezing

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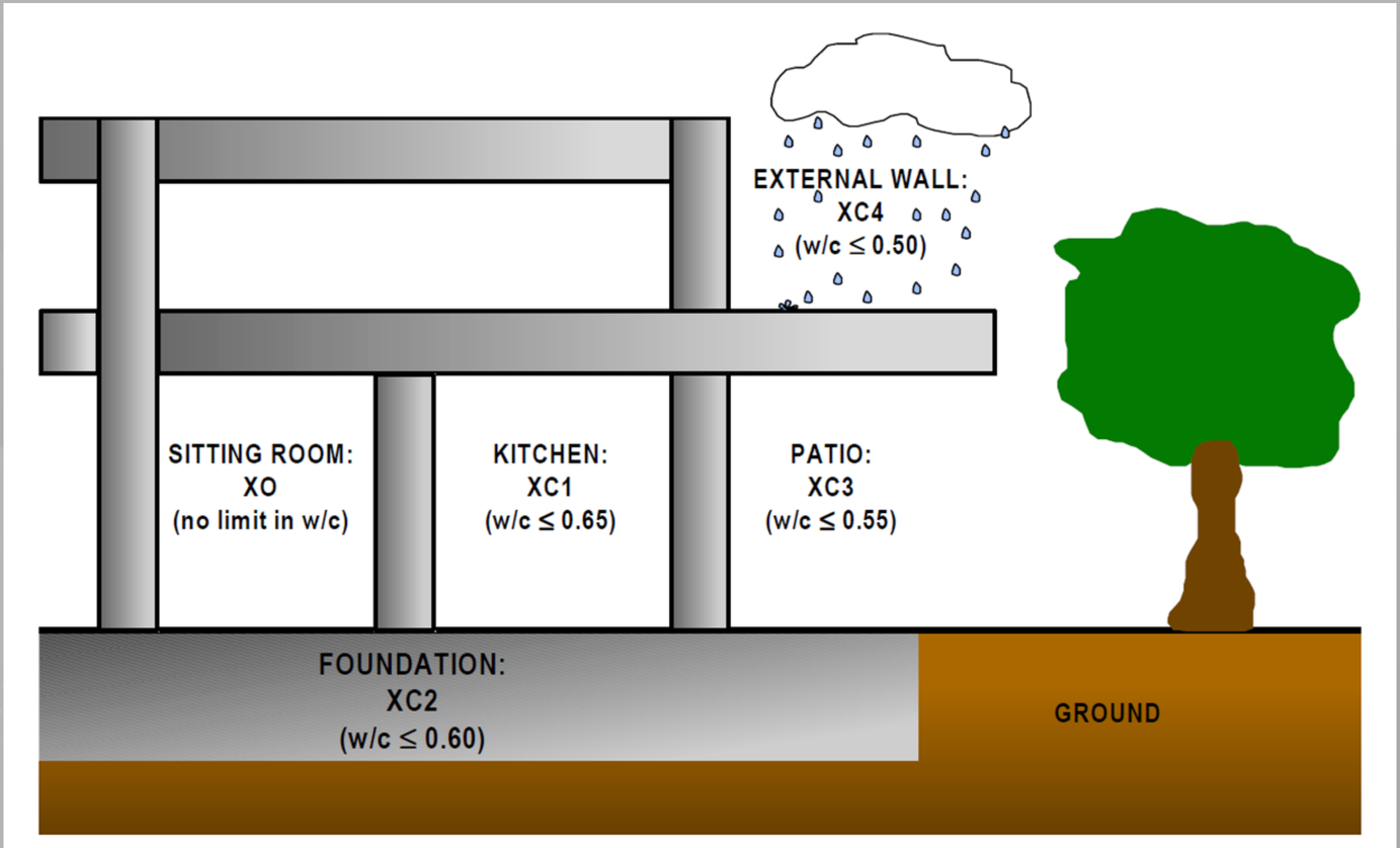
Exposure classes – chemical attack XA

- leaching of calcium hydroxide
- ingress of harmful substances, such as sulfates or nitrates

Class designation	Description of the environment	Informative examples where exposure classes may occur
	Chemical attack	
X A 1	Slightly aggressive chemical environment according to Table 2.2.2	Concrete in treatment plants; slurry containers
X A 2	Moderately aggressive chemical environment according to Table 2.2.2	Concrete components in contact with sea water; components in soil corrosive to concrete
X A 3	Highly aggressive chemical environment according to Table 2.2.2	Industrial effluent plants with effluent corrosive to concrete; silage tanks; concrete structures for discharge of flue gases

Exposure classes examples



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Requirements for each exposure class

The requirements for each exposure class shall be specified in terms of:

- permitted types and classes of constituent materials
- maximum water/cement ratio
- minimum cement content
- minimum concrete compressive strength class (optional)

and if relevant

- minimum air-content of the concrete

Recommended limiting values for composition and properties of concrete

	Exposure classes																	
	No risk of corrsion or attack	Carbonation-induced corrosion				Chloride-induced corrosion						Freeze/thaw attack				Aggressive chemical environments		
						Sea water			Chloride other than from sea water									
	XO	XC1	XC2	XC3	XC4	XS1	XS2	XS3	XD1	XD2	XD3	XF1	XF2	XF3	XF4	XA1	XA2	XA3
Maximum w/c	–	0.65	0.60	0.55	0.50	0.50	0.45	0.45	0.55	0.55	0.45	0.55	0.55	0.50	0.45	0.55	0.50	0.45
Minimum strength class	C12/15	C20/25	C25/30	C30/37	C30/37	C30/37	C35/45	C35/45	C30/37	C30/37	C35/45	C30/37	C25/30	C30/37	C30/37	C30/37	C30/37	C35/45
Minimum cement content (kg/m³)	–	260	280	280	300	300	320	340	300	300	320	300	300	320	340	300	320	360
Minimum air content (%)	–	–	–	–	–	–	–	–	–	–	–	–	4.0 [a]	4.0 [a]	4.0 [a]	–	–	–
Other requirements													Aggregate in accordance with EN 12620 with sufficient freeze/thaw resistance			Sulphate resisting cement [b]		

[a] Where the concrete is not air entrained, the performance of concrete should be tested according to an appropriate test method in comparison with a concrete for which freeze/thaw resistance for the relevant exposure class is proven.

[b] Moderate or high sulphate resisting cement in exposure Class XA2 (and in exposure Class XA1 when applicable) and high sulphate resisting cement in exposure Class XA3.

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Chloride content Cl

C 30/37 - XC4 - **Cl0,20** - D_{max}32 - C3

- the chloride content of a concrete, expressed as the percentage of chloride ions by mass of cement, shall not exceed the value for the selected class

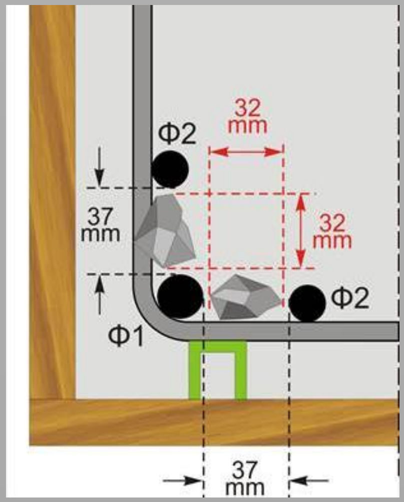
Concrete use	Chloride content class [a]	Maximum chloride content by mass of cement [b]
Not containing steel reinforcement or other embedded metal with the exception of corrosion-resisting lifting devices	Cl 1.0	1.0 %
Containing steel reinforcement or other embedded metal	Cl 0.20	0.20 %
	Cl 0.40	0.40 %
Containing prestressing steel reinforcement	Cl 0.10	0.10 %
	Cl 0.20	0.20 %

Maximum nominal upper aggregate size D_{max}

C 30/37 - XC4 - Cl0,20 - **D_{max}32** - C3

D_{max}:

- **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**

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Classification by consistence

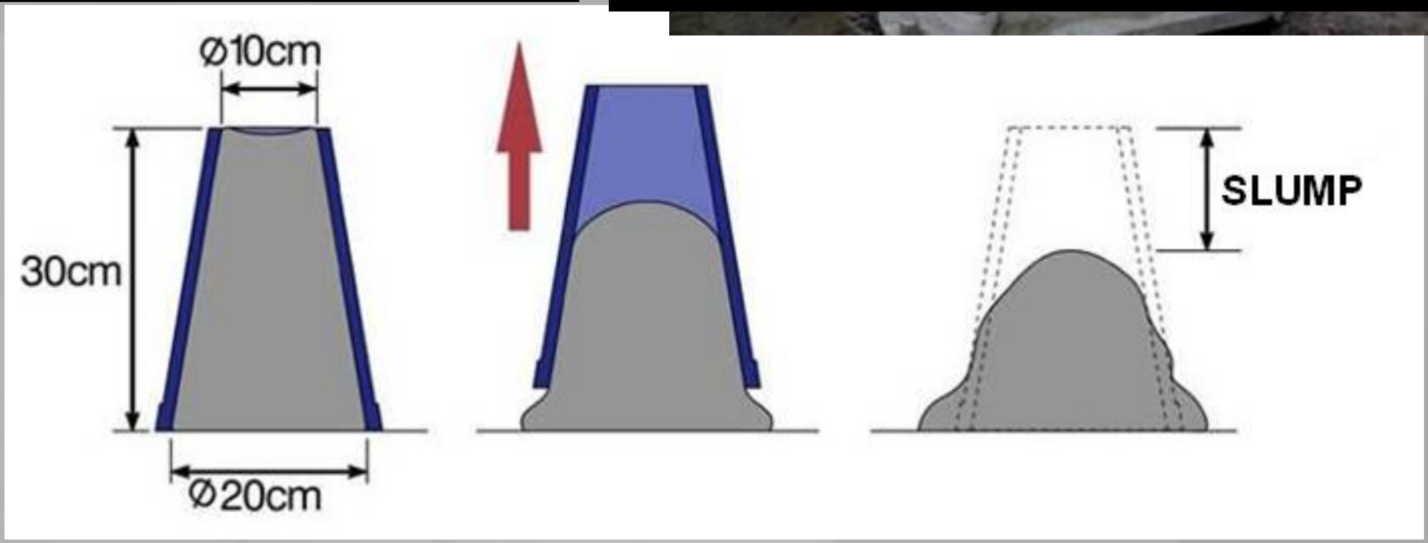
C 30/37 - XC4 - Cl0,20 - D_{max}32 - **C3**

- **the workability of concrete**
- consistence
  - the behaviour of the fresh concrete during mixing,handling, delivery and placing, during compaction and surface smoothing
  - unlike workability, the consistence of the fresh concrete can be measured
- **S - slump**
- **F - flow**
- **V - VeBe**
- **C - compaction**

Slump classes S

- **Abrams cone**

Class	Slump in mm
S1	10 to 40
S2	50 to 90
S3	100 to 150
S4	160 to 210
S5 [1]	≥ 220



Flow classes F

Class	Flow diameter in mm
F1 [1]	≤ 340
F2	350 to 410
F3	420 to 480
F4	490 to 550
F5	560 to 620
F6 [1]	≥ 630

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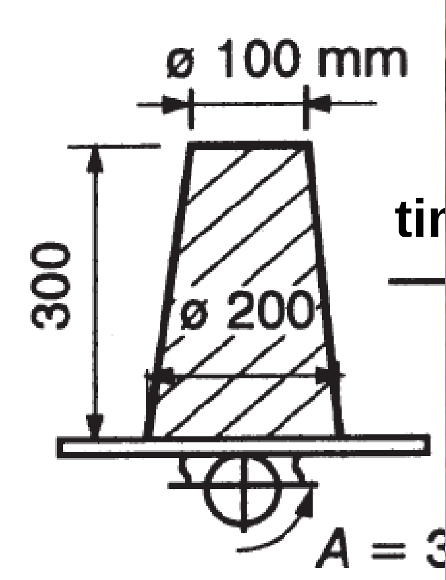
Vebe classes V

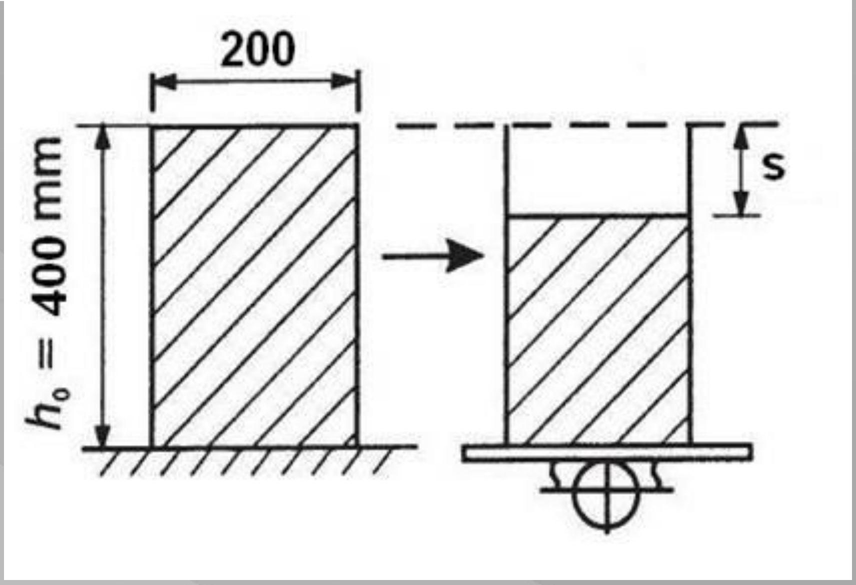
Class	Vebe time in seconds
V0 [1]	≥ 31
V1	30 to 21
V2	20 to 11
V3	10 to 6
V4 [2]	up to [illegible]



Compaction classes C

Class	Degree of compactability
C0 [1]	≥ 1.46
C1	1.45 to 1.26
C2	1.25 to 1.11
C3	1.10 to 1.04

$$c = \frac{h_0}{h_0 - s}$$



Concrete mix proportion design

1. **definition of requirements** (influence of environment, type of construction, load)
2. **choice of components** (cement type, aggregates gradation, admixtures)
   - workability is determined for the type of work
   - the maximum aggregate size is chosen
   - air content is determined from durability requirements
   - the w/c is selected to satisfy strength and durability
3. **design of composition**
4. **experimental verification of design**

Basic principles for design

- the mix should be workable
- as little cement as possible should be used
- as little water as possible should be used
- coarse and fine aggregate should be proportioned to achieve a dense mix
- the nominal maximum size of aggregate should be as large as possible
- the water-to-cement ratio will determine the compressive strength

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Experimental verification of design

1. determination of consistence (workability)
2. change of composition for demanded consistence
3. determination of strength
4. change of composition for demanded strength without influence on the workability
5. determination of definitive composition

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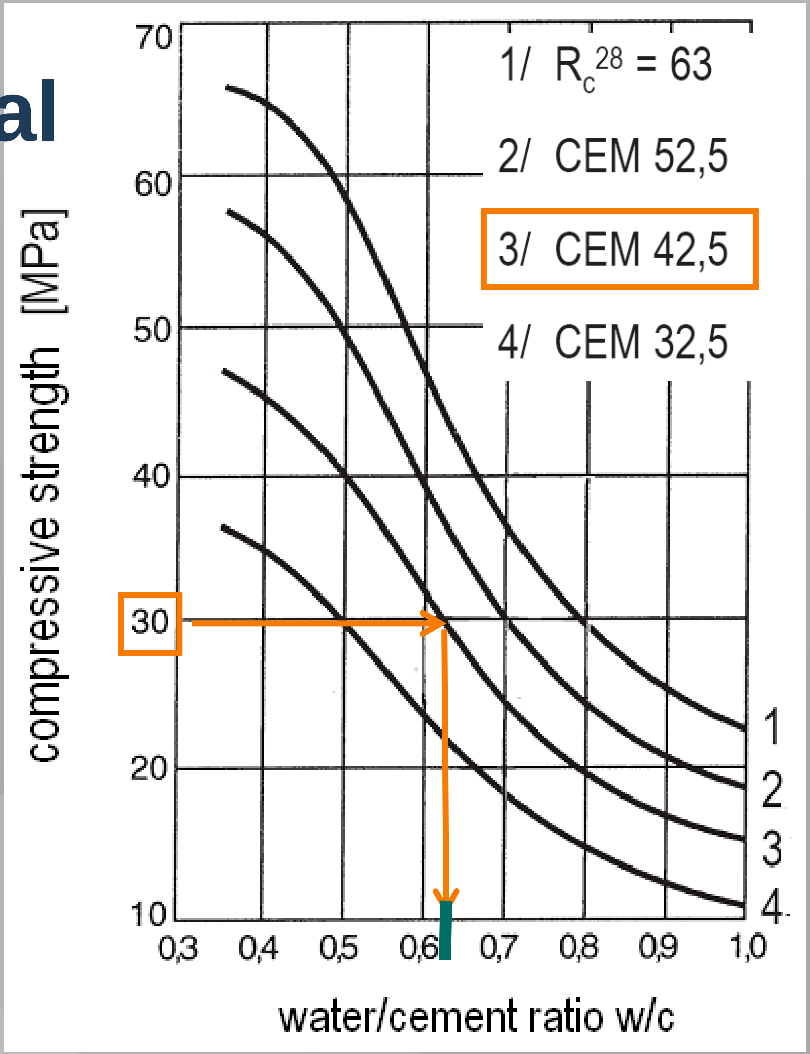
Concrete mix proportion design

According empirical amount of water

1. Find w/c for chosen cement type and demanded strength.



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Concrete mix proportion design

2. Determinate amount of water in $1m^3$ for chosen consistence and aggregate size
3. Calculate m_c from amount of water and w/c

$$m_c = \frac{m_v}{w}$$

consistence	Aggregates granulometry											
	wA_8	B_8	C_8	A_{16}	B_{16}	C_{16}	A_{32}	B_{32}	C_{32}	A_{63}	B_{63}	C_{63}
C 0	160	178	197	139	160	183	133	152	171	123	139	163
S 1	166	184	205	145	166	189	137	158	177	127	145	169
S 2	176	194	217	155	176	200	145	167	188	135	155	180
S 3	192	212	135	170	192	217	159	181	207	148	170	197
S 4	204	227	250	181	204	232	171	197	223	159	181	211

Concrete mix proportion design

4. Determinate the volume of other constituents according the equation:

$$\frac{m_c}{\rho_c} + \frac{m_v}{\rho_w} + \frac{m_k}{\rho_a} + \left(\frac{m_p}{\rho_p}\right) = 1 - \frac{V_z}{100}$$

cement (ρ_c= 3100 kg.m^{-3})

water (ρ_w= 1000 kg.m^{-3})

aggregates (ρ_a= 2650 kg.m^{-3})

additions (ρ_p= 2100 kg.m^{-3})

Air content (%)

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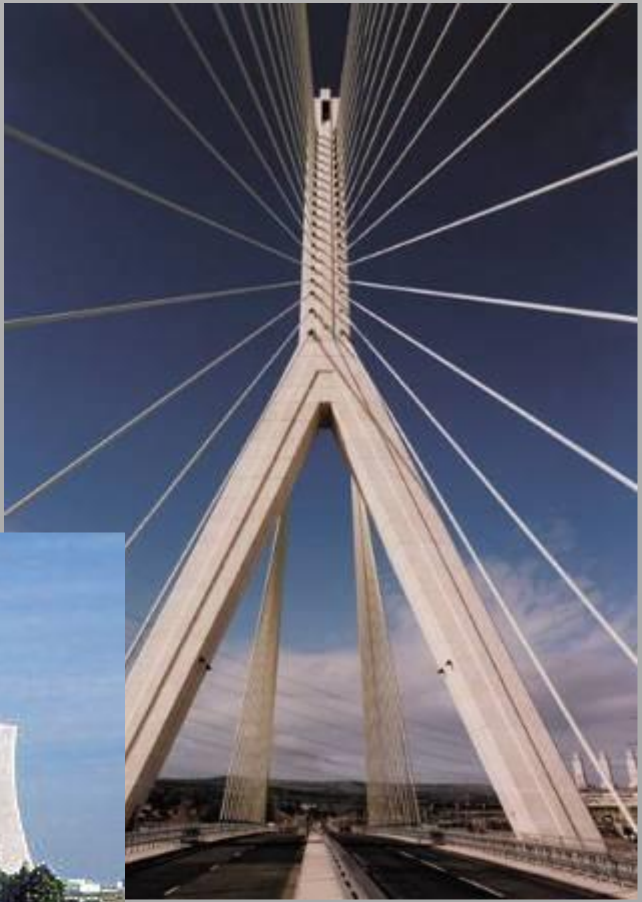
Concrete types

- plain (non reinforced) concrete
- reinforced concrete
- prestressed concrete
- fiber-reinforced c.
- lightweight c. ($\rho_V < 2000$ kg.m^3)
- high-performance and special concretes
  - self-compacting
  - high-strength c.
  - waterproof c.
  - sprayed c.
  - fair-faced c.
  - colored c

Reinforced and prestressed concrete

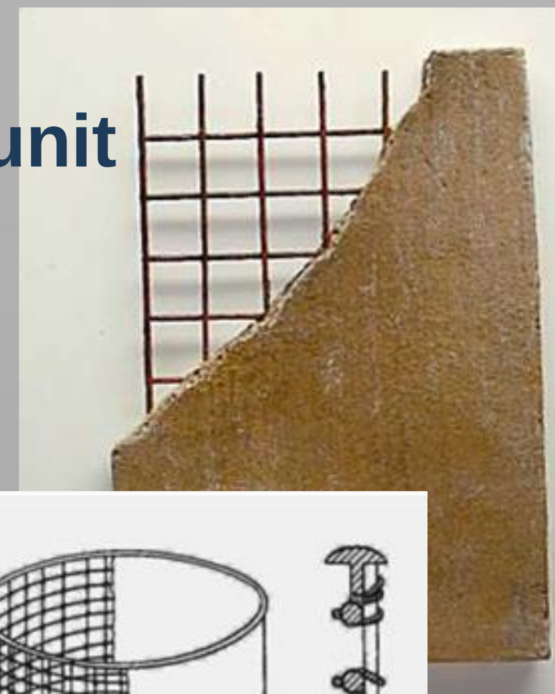


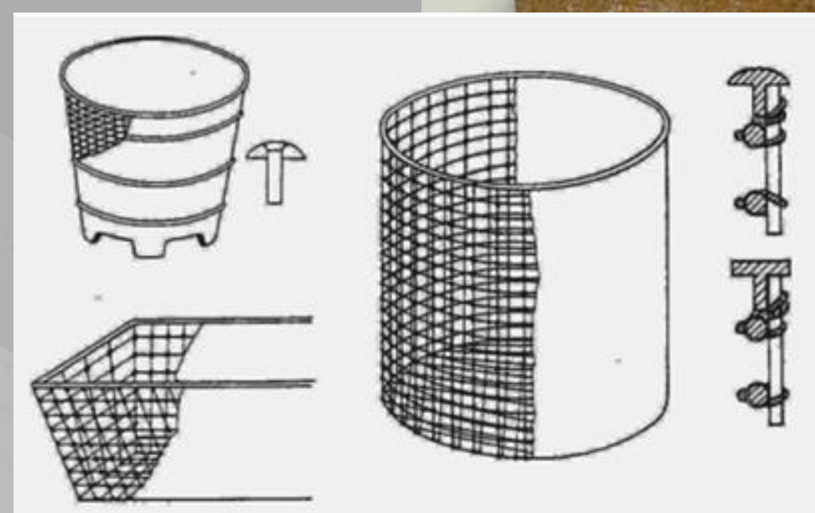
Reinforced concrete

- **combining plain concrete and reinforcing steel**
- **the system behaves as a unit**

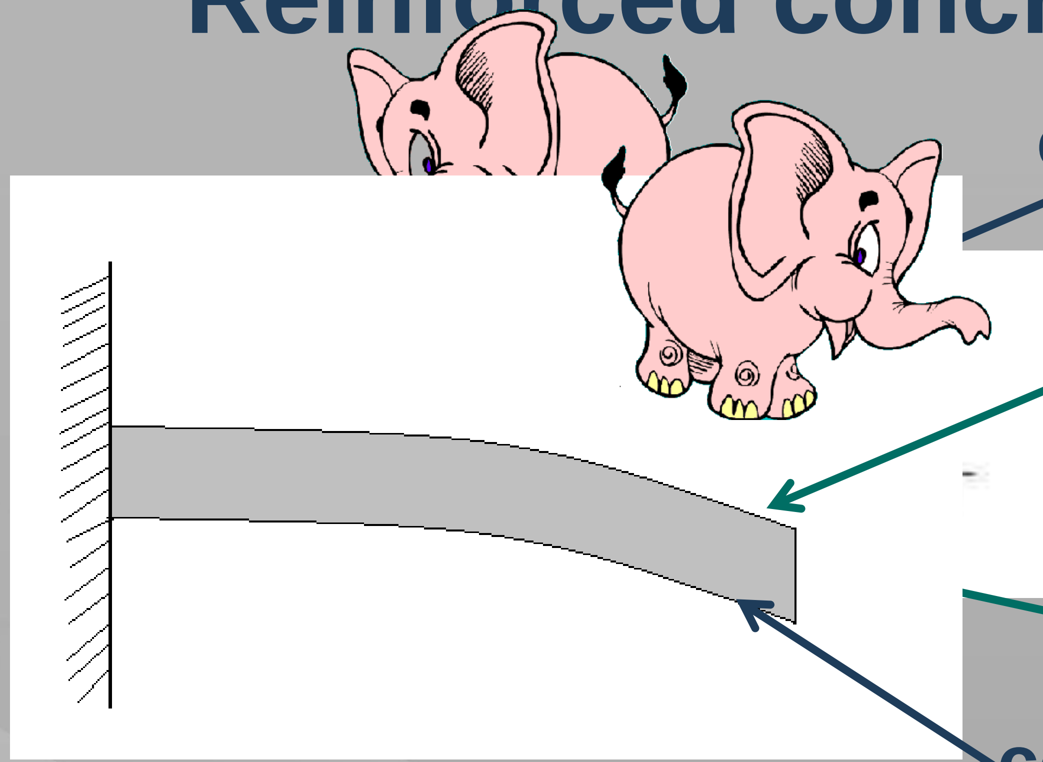
Joseph **Monier**

1823-1906





Reinforced concrete



- good bond between steel and concrete
- thermal compatibility ($\alpha_t \cong 12.10^{-6}\ K^{-1}$)
- good material tolerance

Reinforcing steel

- **bars**
- **grids**
- **fibers**
- **strands, cables** (prestressing)

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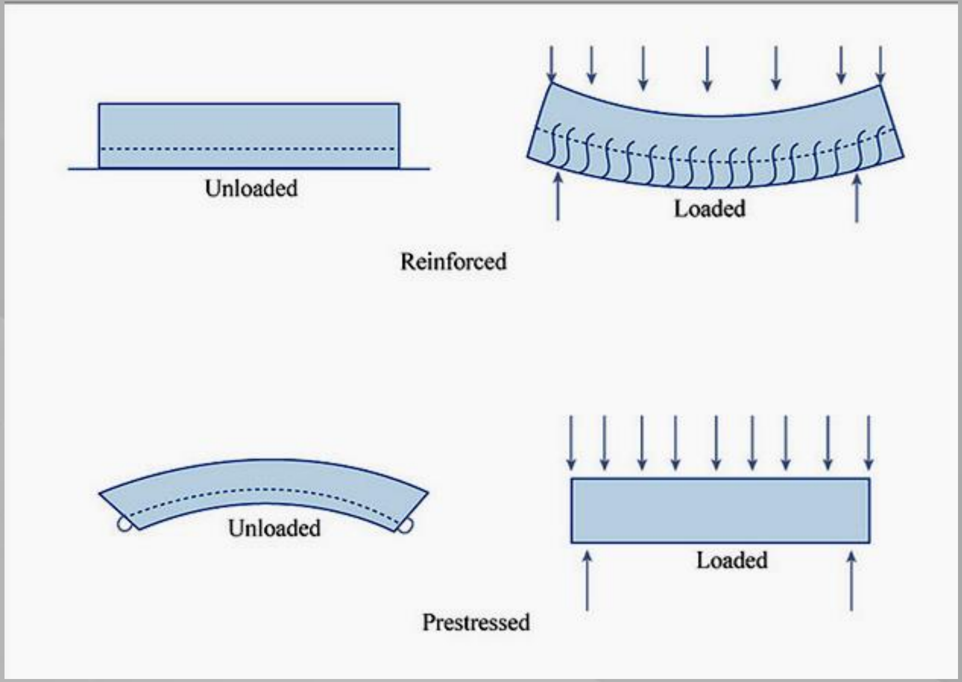
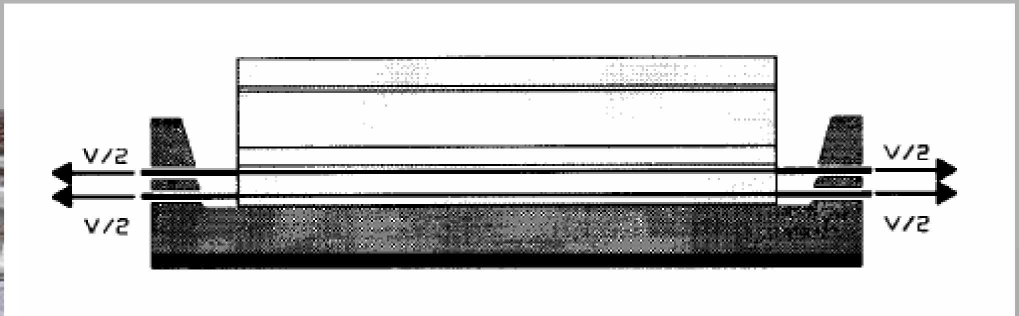
Prestressed concrete

- compressive stresses induced by high-strength steel tendons in a concrete member before loads are applied, will balance the tensile stresses imposed in the member during service



Prestressed concrete

- **pre-tensioned concrete**
  - concrete is cast around already tensioned tendons



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Prestressed concrete

- **post-tensioned**
  - applying compression after pouring concrete and the curing process (*in situ*)

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Prestressed concrete

Opera, Sydne

Capital Gate, Abu Dhabi

Morandi Bridge, Genoa

Incheon Bridge, South Corea

CN Tower, Toronto

Building materials

Lightweight concretes

- **bulk density < 2000 kg.m^3**
  - pervious
  - lightweight aggregates
  - foamed

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Lightweight concretes

+ less need for structural steel reinforcement
+ smaller foundation requirements
+ better fire resistance
+ better thermal properties

– usually lower strength
– higher cost
– higher shrinkage
– higher water absorption

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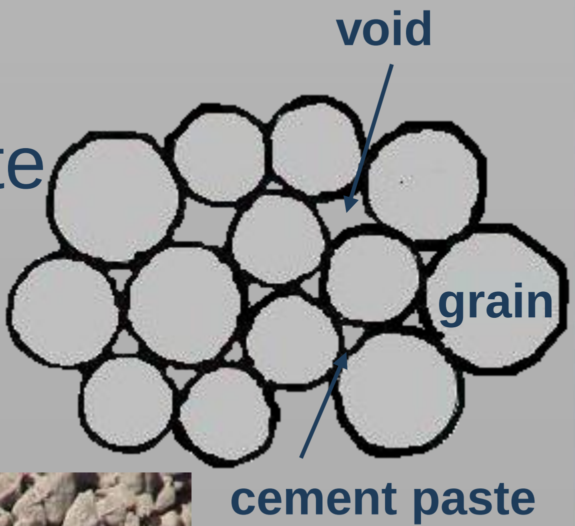
Pervious concretes

- little or no fine aggregate and just enough cementitious paste to coat the coarse aggregate particles while preserving the interconnectivity of the voids



Properties:

- compressive strength
  1-10 MPa
- bulk density
  900 -1400 $kg.m^3$
- very high permeability

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Pervious concrete

- **pavements**
  - drainage
  - noise reduction
- **noise protection walls**

Concretes with lightweight aggregates

Lightweight aggregates:

- natural (pumice, scoria, volcanic cinders, tuff, and diatomite)
- thermal treatment of natural raw materials (clay, slate, shale, perlite)
- from industrial by-products (fly ash, slag)






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Concretes with lightweight aggregates - LWAC

- compressive strength similar to normal concretes (up to **45 MPa**)

- **ρ_v = 1000 - 2000 kg.m^3**
- **high-strength lightweight concretes** (HSLW) – strength up to **90 MPa**

- aggregates require wetting prior to use
- worse pumping
- worse finishing

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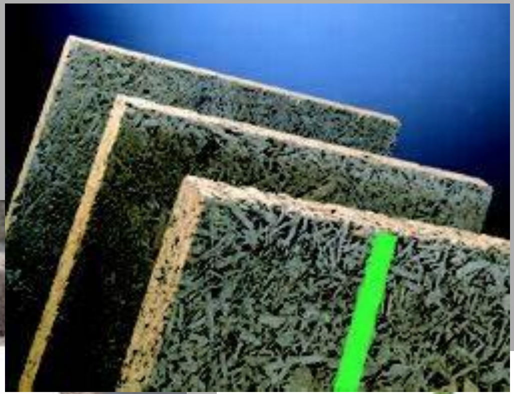
Concretes with organic aggregates

- wood particles (need mineralization)
- natural fibers (hemp, sisal, bamboo, coir)
- foamed plastics (EPS, PP)



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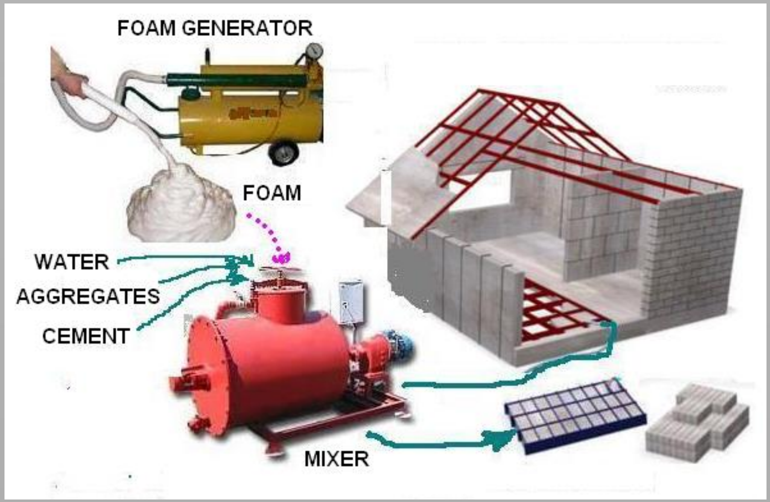
Cellular concretes

- **foamed concrete**
  - mixing of concrete with in advance prepared foam
  - foam is prepared in foam generator
- **aerated autoclaved concrete – AAC**
  - foaming agents, which generates gas in concrete due to chemical reaction



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High performance concretes

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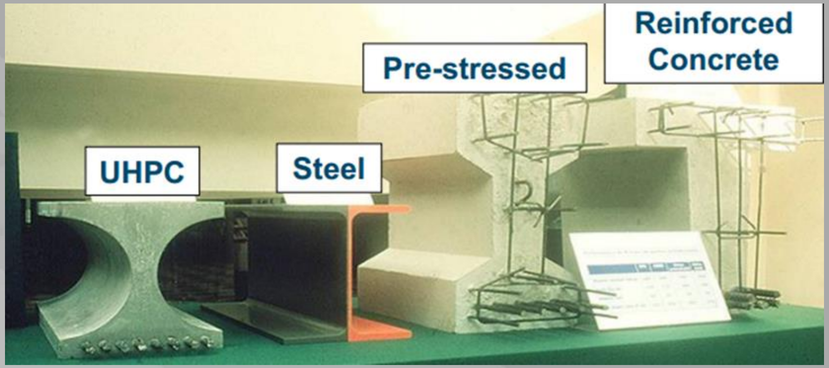
High performance concrete - HPC

- concrete that meets special performance and uniformity requirements that cannot always be obtained using conventional ingredients, normal mixing procedures, and typical curing practices

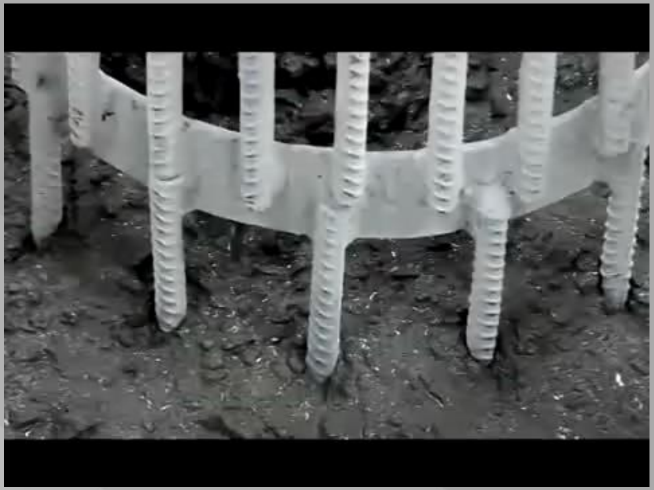
Characteristics:

- ease of placement and consolidation without affecting strength
- long-term mechanical properties
- early high strength
- volume stability
- longer life in severe environments



Self- consolidating concrete SCC

- highly flowable, non-segregating concrete that spreads into place, fills formwork, and encapsulates even the most congested reinforcement, all without any mechanical vibration
- developed in 1980s — Japan
- strength and durability same as conventional concrete



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Self- consolidating concrete SCC

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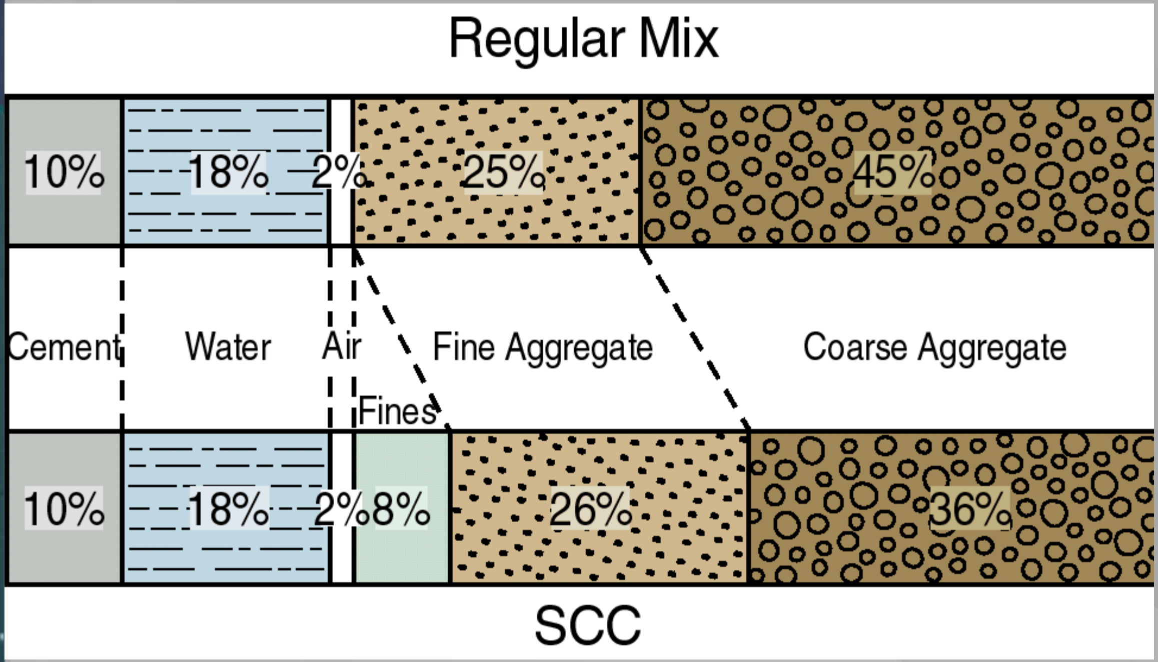
Self- consolidating concrete

- **increased amount of**
  - fine material (i.e. fly ash or limestone filler)
  - superplasticizers



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High-strength concrete - HSC

- **compressive strength**
  - **60- 90 MPa** - HSC
  - **100-180 MPa** - UltraHSC
- highly impermeable
  - the curing is very important
- brittle
  - high strength and increased stiffness
- low water content (< 0.38)
  - some cement grains act as aggregate grains (not all of the cement can be hydrated)

Burj Khalifa, 828 m

High-strength concrete - HSC

Components:

- portland cement
- latent hydraulic and pozzolanic materials
  - large quantities (5% - 20%)
- superplasticizers
- high strength aggregates with a suitable particle surface (angular), reduced particle size (< 32 mm)
- admixtures to ensure maximum de-aeration
- w/c ~ 0,28

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APC – Advanced Permormance Composites

Musashi Kosugi Towers, Tokio

Component	Amount / 1 m^3 of concrete
Cement with silica fume	**1024 kg**
Fine aggregates	**436 kg**
Coarse aggregates	**840 kg**
Mixing water	**155 l**
Polypropylene fibres	**2 kg**
Steel fibers	**40 kg**
Superplasticizers	**PC**

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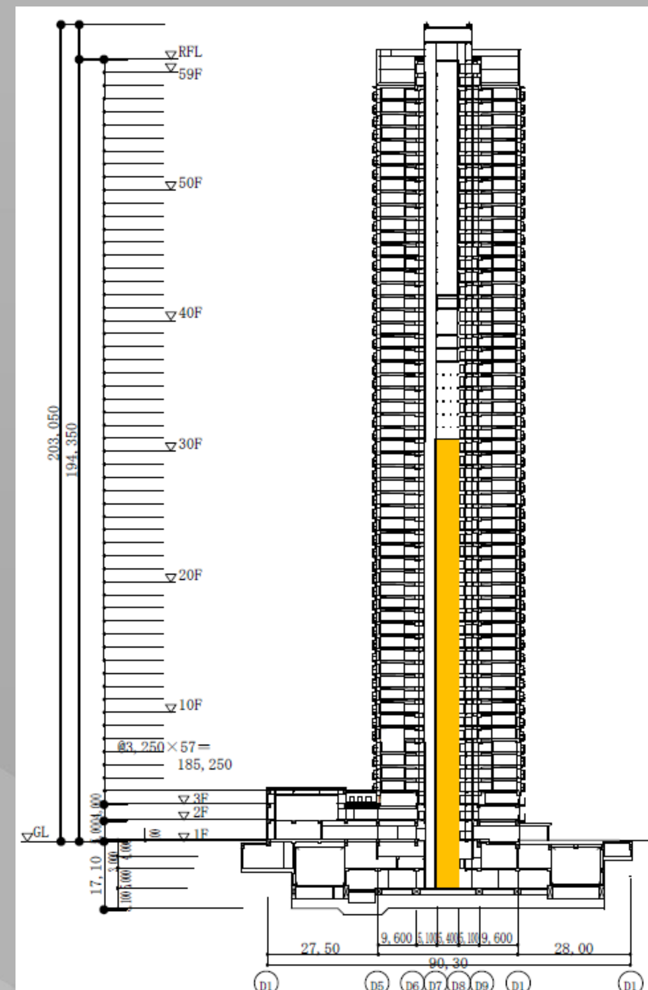
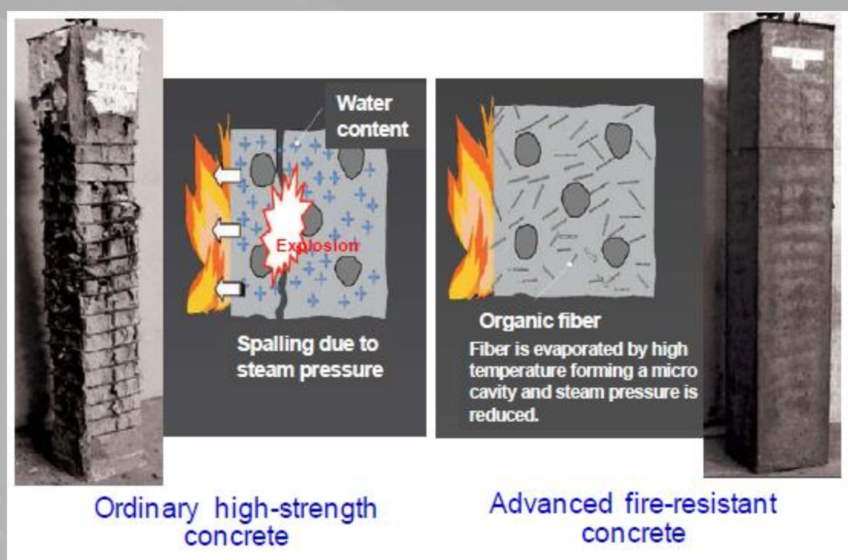
APC - Musashi Kosugi Towers, Tokio

- compressive strength: **150 MPa**
- w/c ratio: **0.15**
- flow diameter: **600 mm**
- air content: **2%**





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Special concretes

Building materials

Waterproof concrete

- **reduced capillary porosity**
  - suitable particle-size distribution
  - low w/c ratio
  - additional sealing of the voids with pozzolanic reactive material
  - careful and correct compaction of the concrete

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Sprayed concrete

- a mixture of cement, aggregate and water projected pneumatically from a nozzle into place to produce a dense homogeneous mass.

- **wet process** (Shotcrete)
  - the concrete mix is supplied in the wet form and is pumped to the spraying nozzle where accelerating agent is added
- **dry process** (Gunite)
  - material is conveyed in a dry or semi dry state using compressed air to the nozzle where water is added

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Sprayed concrete

Advantages

- high strength, low permeability, high durability
- reduction in formwork saving time and money
- high early strength gain
- low water / cement ratio
- good adhesion and bond strengths

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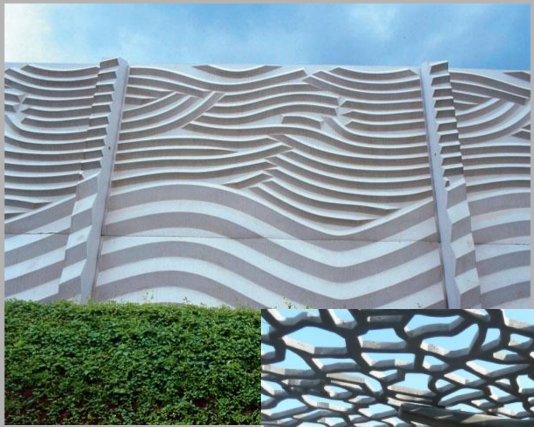
Fair faced concrete

- smooth concrete surface
- uniform appearance
- low-void (max. proportion of voids 0,3 – 0,6 % of test surface)

Fair faced concrete



Rules:

- suitable concrete mix
  - suitable aggregates
- good formwork
  - absolutely impervious
- right quantity of a release agent
- suitable placement method
- correct installation
  - compaction, placing, prevention of bleeding
- thorough curing

Light transmitting concrete

- **Litracon**
- 4 % optical fibers
- ρ_v = 2100 - 2400 kg.m^3
- compressive strength 50 MPa
- price: t.100 mm – 2140 € / m^2

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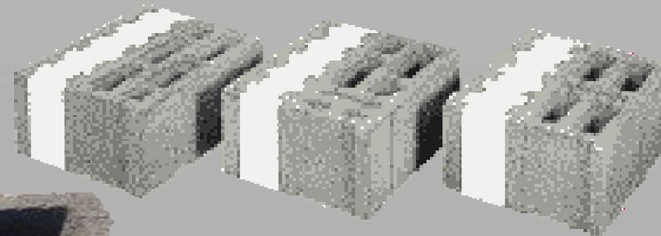
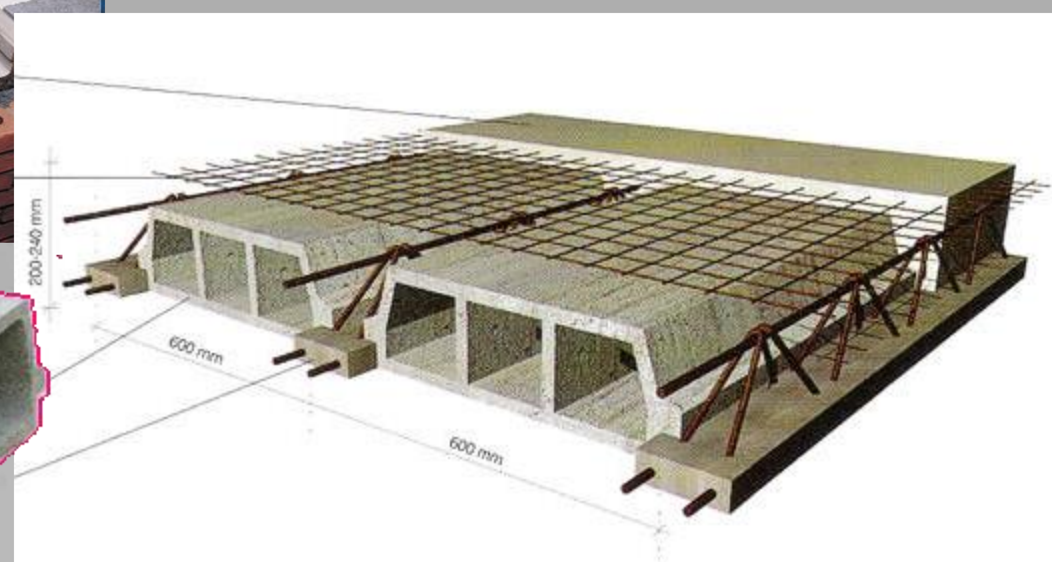
Concrete blocks and ceiling

- masonry blocks
- ceiling elements





Concrete tiles

- roof tiles
- floor tiles

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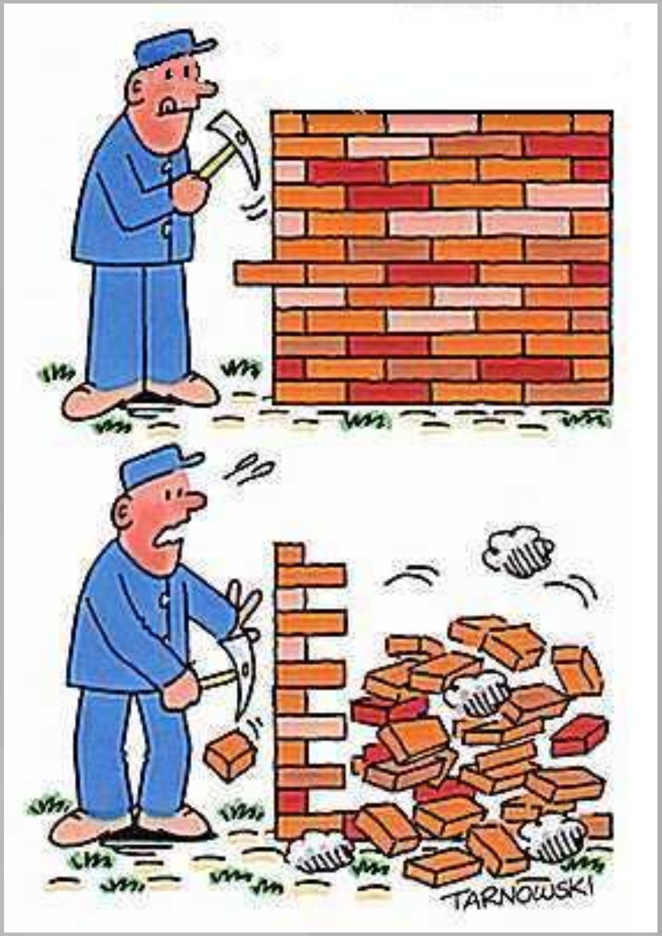
Mortars



Mortars

- **binder + <u>fine</u> aggregates + (additives) + water**

Use:

- masonry mortars
- plastering and rendering m.
- laying adhesives, grouts, screeds

Manufacture:

- site made
- factory made
- semi-finished

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Mortar components

Binder:

- **clay**
- **cement**
- **cement + lime**
- **lime**
- **gypsum**
- **gypsum + lime**

Aggregates

- **sand**
- **blast furnace slag**
- **ash**
- **perlite**
- **polystyrene**

Additives:

- plastificating a., fibers, pigments

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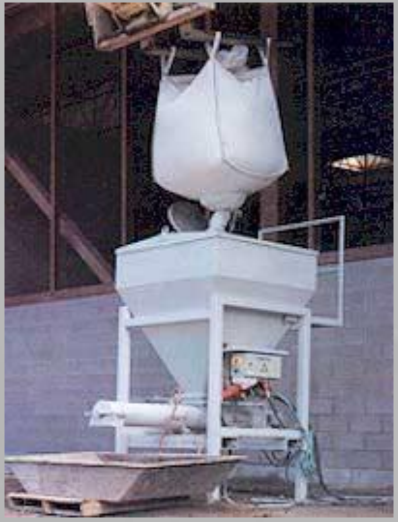
Masonry mortars

- **site-made**
  - **sand : cement : hydrated lime =**
  - **= 6 : 1 : 1**
  - **sand : cement = 4 : 1**

- **factory made** (EN 998-2)



Masonry mortars - definitions

- **general purpose (G)**
  - satisfies general requirements, without special characteristics
  - prescribed and/or designed
- **thin layer (T)**
  - a maximum aggregate particle size of 2 mm
- **lightweight (L)**
  - a dry bulk density below 1400 kg/m^3

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Brick laying – horizontal joints

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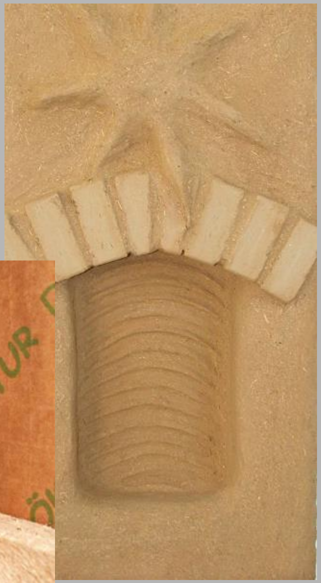
Rendering mortars

- site-made – exceptionally (restoring works)
- **factory made**
  - lime, cement, lime-cement - EN 998-1
  - gypsum - EN 13279

Rendering mortars

- **general purpose (GP)**
- **lightweight (LW)**
  - a dry hardened bulk density of less than 1300 kg/m^3
- **colored (CR)**
- **one coat for external use (OC)**
- **thermal Insulating (T)**
- **renovation (R)**
  - for use on moist masonry walls containing soluble salts

Clay renders



- **clay + sand + (fibers)**
- outer – restoring works
- inner – also in modern interiors (moisture regulation)

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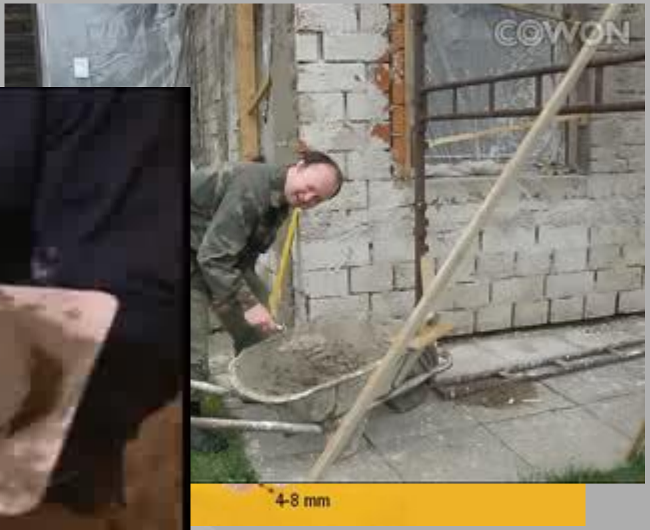
Classical and one coat renders

- **classical render** – **15-**
  mm
  (primer, undercoat, fini
  coat)

- **one coat renders** – **4-8 mm**
  - gypsum
  - lime-cement
  - acrylic
  - silicone
  - silicate



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Thermal insulating mortars

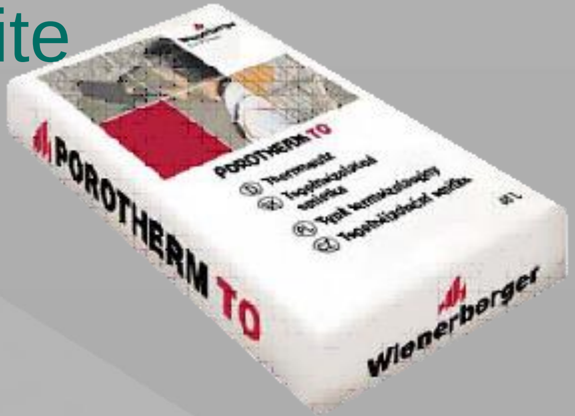
- **masonry mortars**

  (λ = 0,2 – 0,6 W.m^{-1}.K^{-1})

  - thermal insulating masonry

- **plaster** (λ = 0,09 – 0,12 W.m^{-1}.K^{-1})
  - worse effect than (ca 1/4) than ETICS *

- **lightweight aggregates**(perlite burned clay aggregates, polystyrene) or **foaming**



* External Thermal Insulating Composite System

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Autoclaved products

Autoclave curing

- curing of products in special vessels (**autoclaves**), with an environment of steam with high pressure and temperature
- **hydrothermal hardening of silicate materials** (temperature ca 180 °C and pressure 0,8 MPa)
- after 16 -18 hours materials obtain the final strength
- after curing in autoclave non-hydraulic binders became hydraulic (quartz sand reacts with calcium hydroxide to form calcium silica hydrate)

Autoclaves for AAC manufacture

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Aerated autoclaved concrete - AAC

Aerated autoclaved concrete

Composition:

- **binder** (lime, cement)
- **silicate materials**
  - sand – white AAC
  - ash – grey AAC
- **gas forming (foaming) admixture**
  - Al powder, Al paste
- **water**

Aerated autoclaved concrete

Foaming:

- $2\ Al + 3\ Ca(OH)_2 + 6\ H_2O \rightarrow 3\ CaO\ .\ Al_2O_3\ .\ 6H_2O + 3\ H_2$

foaming gas

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AAC manufacture

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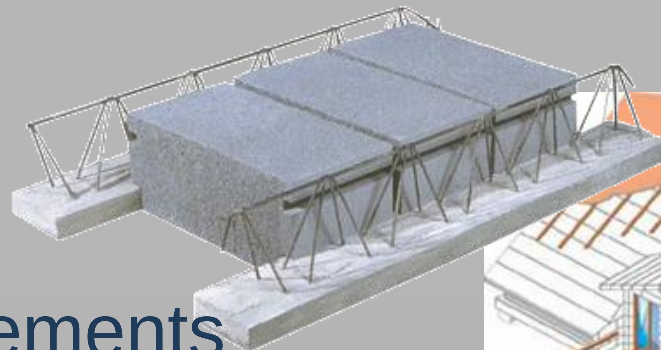
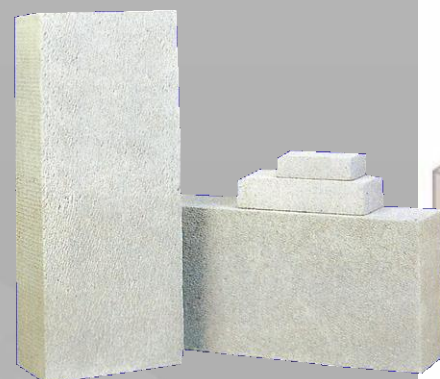
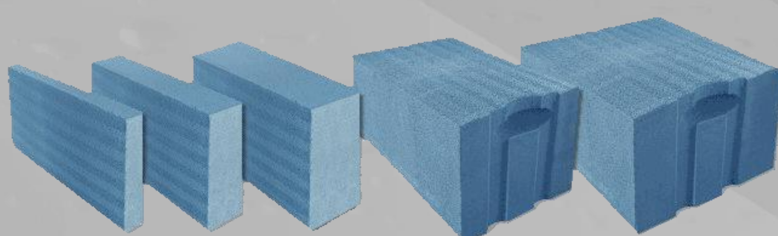
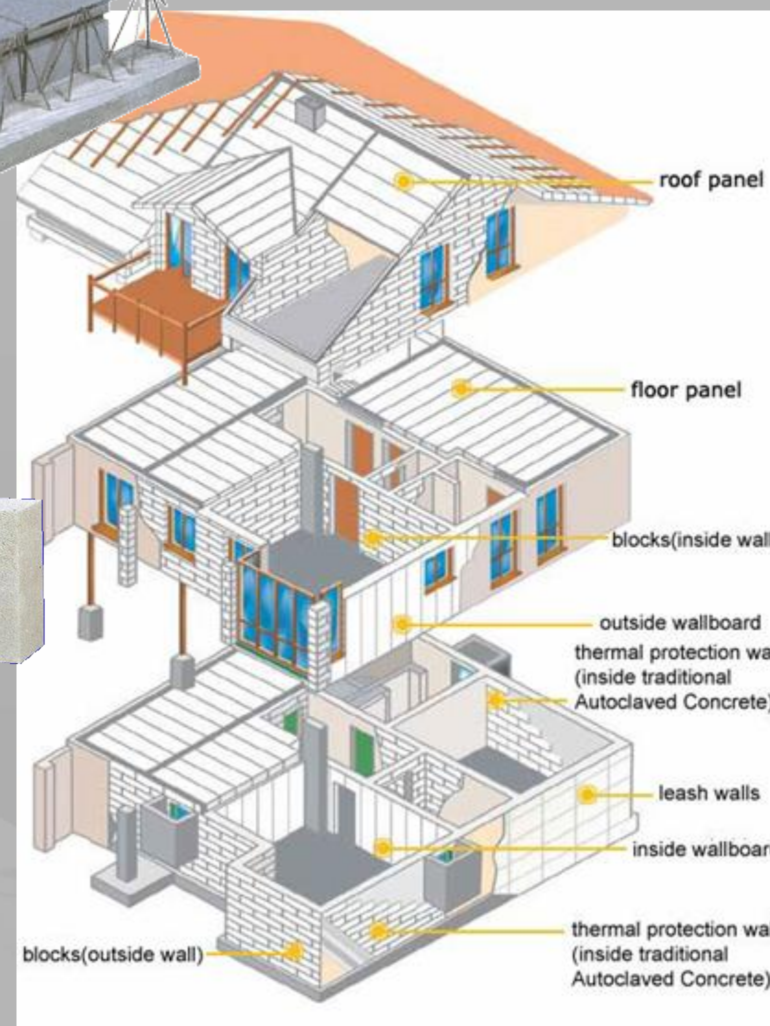
AAC - products



- blocks
- lintels
- ceiling elements
- panels
  - walls
  - partitions
  - floors
- chimney elements







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AAC - properties

- **compression strength classification:**
  - 1,5; 2; 2,5; 3; 3,5; 4; 4,5; 5; 6; 7 (MPa)
- **bulk density classification:**
  - 300 (250 –300); 350; 400; 450; 500; 550;........ 950; 1000 (kg/m^3)
- **λ = 0,11 – 0,17 W.m^{-1}.K^{-1}**
- **water absorptivity ≅ 15 %**

AAC - advantages

- \+ less amount of mortar
- \+ good thermal efficiency
- \+ easy sawing and cutting
- \+ light weight
- \+ easy rendering
- \+ price





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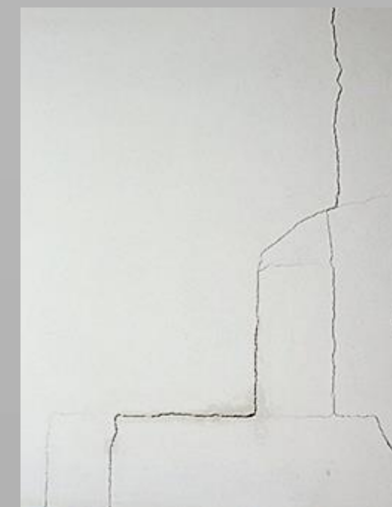
AAC - disadvantages

- high expedition moisture
- long drying
- lower compressive strength
- creeping (cracks)
- volume changes with moisture



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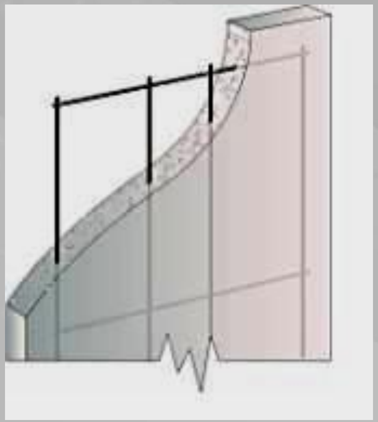
AAC - reinforcing

- after autoclave curing there is no $Ca(OH)_2$ → AAC is not alkalic

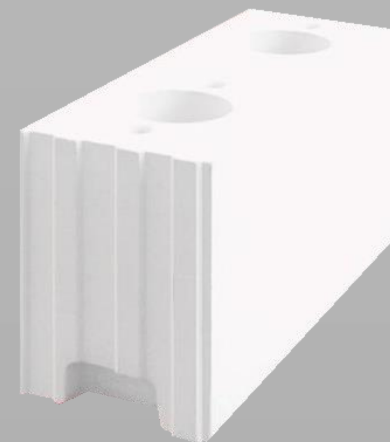
→ **anticorrosive protection of reinforcing steel is necessary !**

- acrylic paint, stainless steel



Autoclaved products

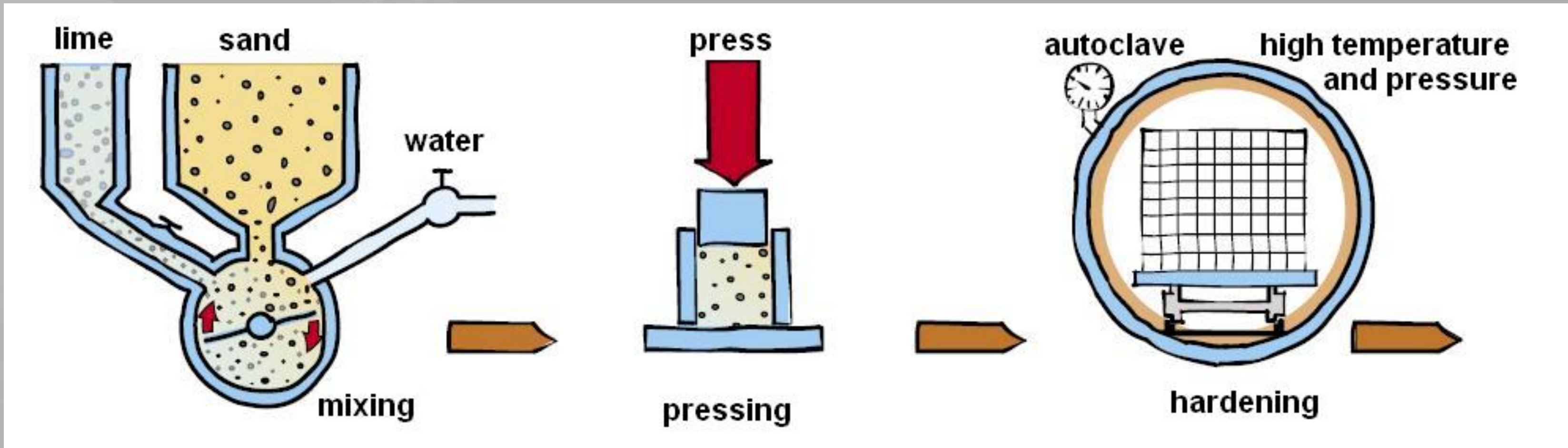
Sand lime masonry elements



Sand lime masonry elements

- **quicklime**

  1 : 10 - 12
- **sand**
- **water**
- pigments



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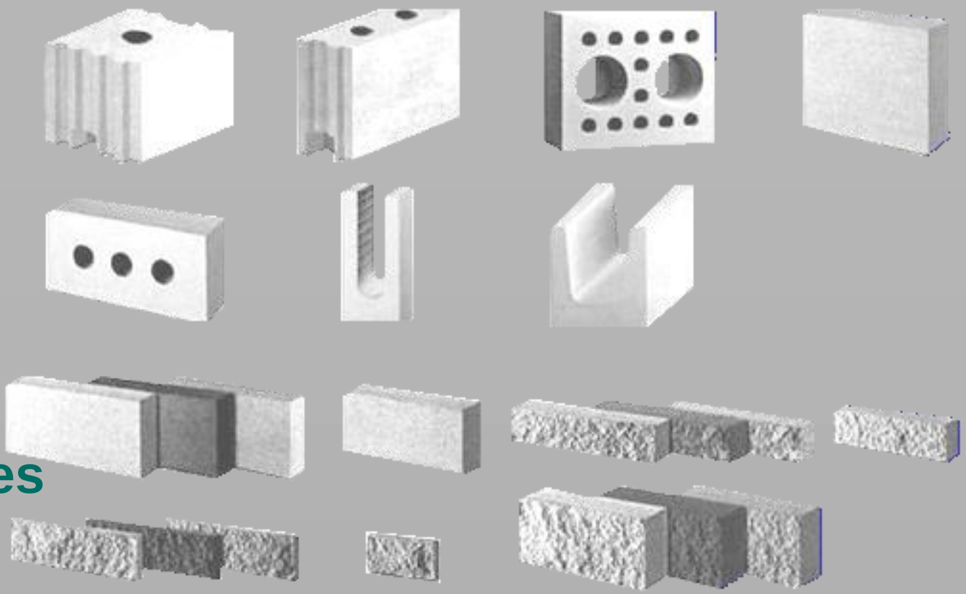
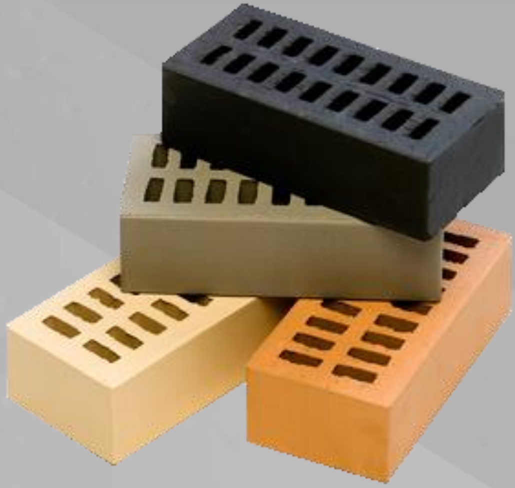
Sand lime masonry elements

- under the action of the high-pressure steam the lime attacks the particles of sand, and a chemical compound of water, lime and silica is produced which forms a strong bond of calcium silicate hydrates with the particles of sand
- **compressive strength**
  R_c = 15 - 40 MPa
- **good frost resistance**
- **ρ_v = 1300 – 2000 kg.m^{-3}**
- **λ = 0,9 W.m^{-1}.K^{-1}**

Sand lime masonry elements

- **bricks**
- **blocks**
  - **full or hollow**
  - **smooth sides or interlocking grooves**
- **wall tiles**
- **lintels**





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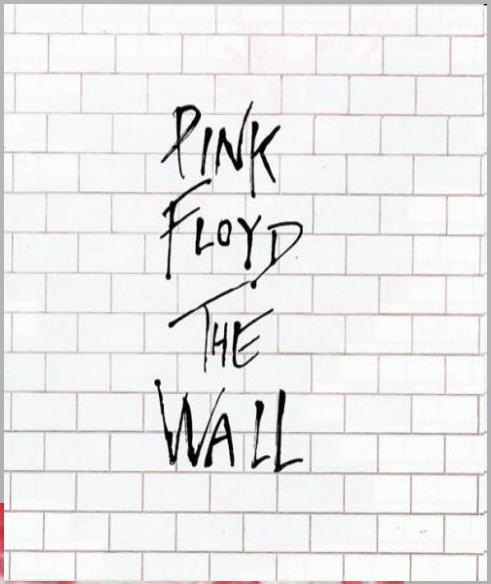
Sand lime masonry elements - advantages

- + high dimensional accuracy
- + smooth surface
- + good frost resistance
- + good fire resistance
- + rendering is not necessary
- + good resistence against chemicals
- + labor saving
- + good thermal accumulation




Sand lime masonry elements - **disadvantages**

- price
- efflorescence
- higher thermal conductivity
- difficult removal of graffiti



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Autoclaved products

Fibre cement

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Fibre cement

Components:

- **cement**
- **formerly asbestos fibers (**Eternit)
  - prohibited (health risk)

now:

- **cellulose fibers**
- **syntetic fibers (PVA)**
- **water**
- **sand** or microfillers
- additives (pigments)

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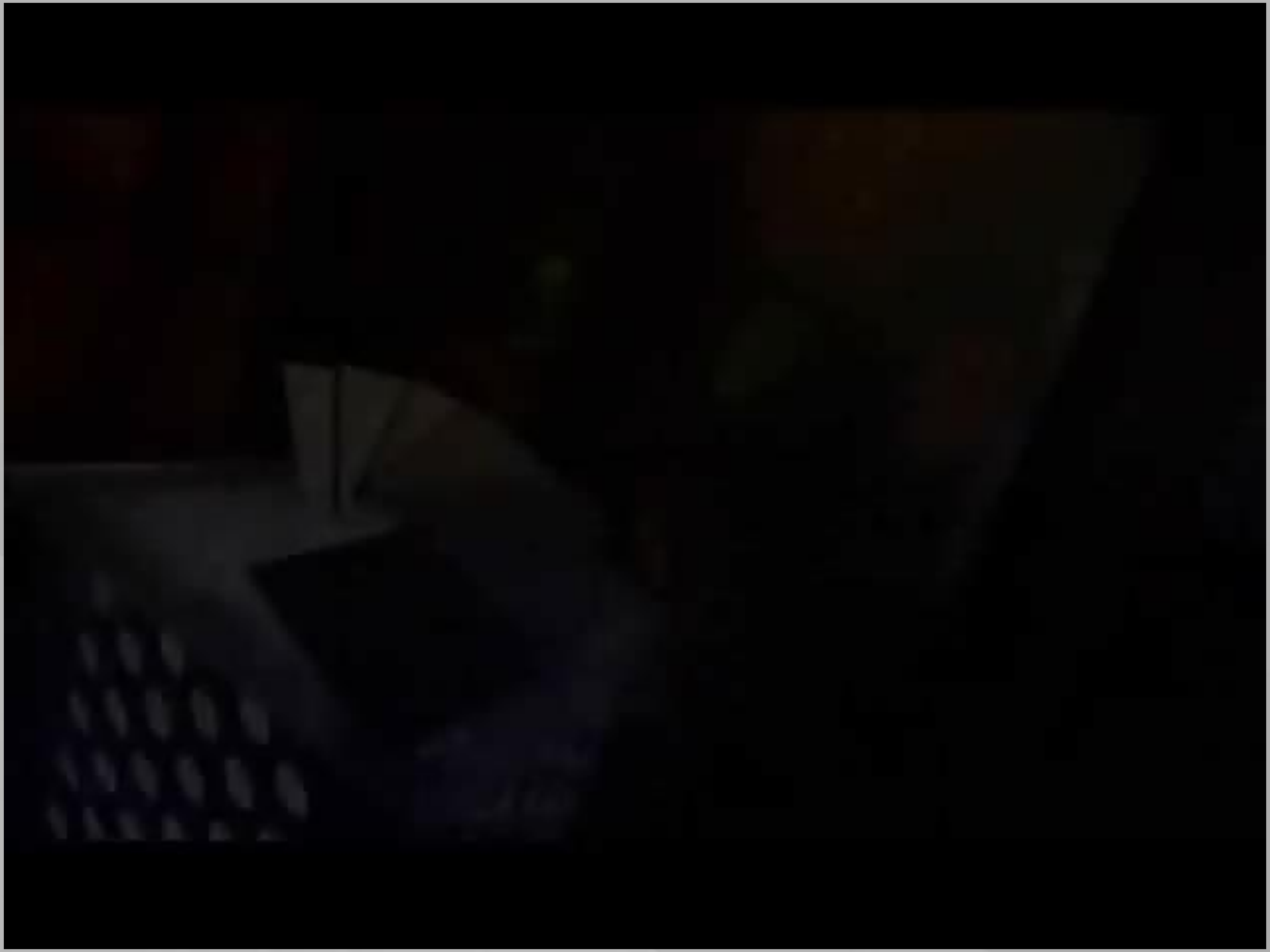
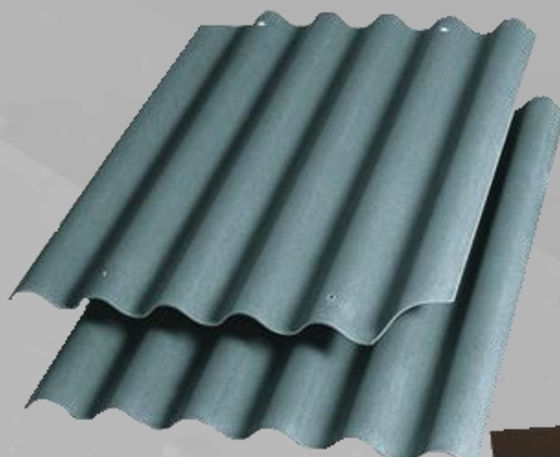
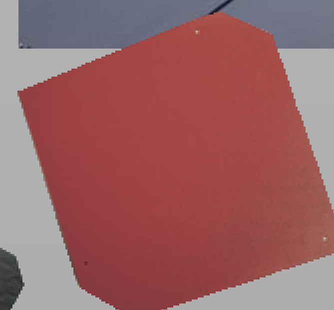
Fibre cement manufacture

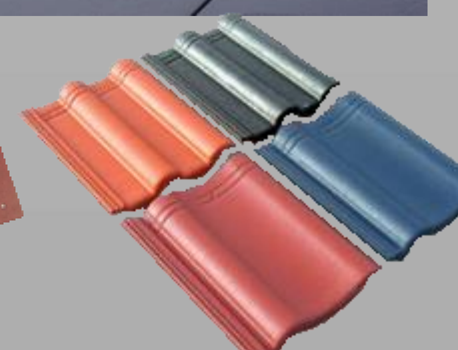


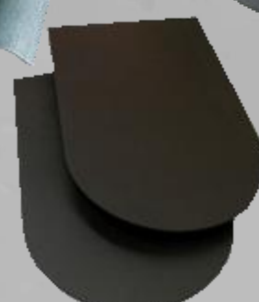
Fibre cement products

- **roofing**
  - **slates**
  - **corrugated sheets**









Fibre cement products

- **cladding**
  - **internal** (fire protection, partition walls, ceilings)
  - **external** (siding)

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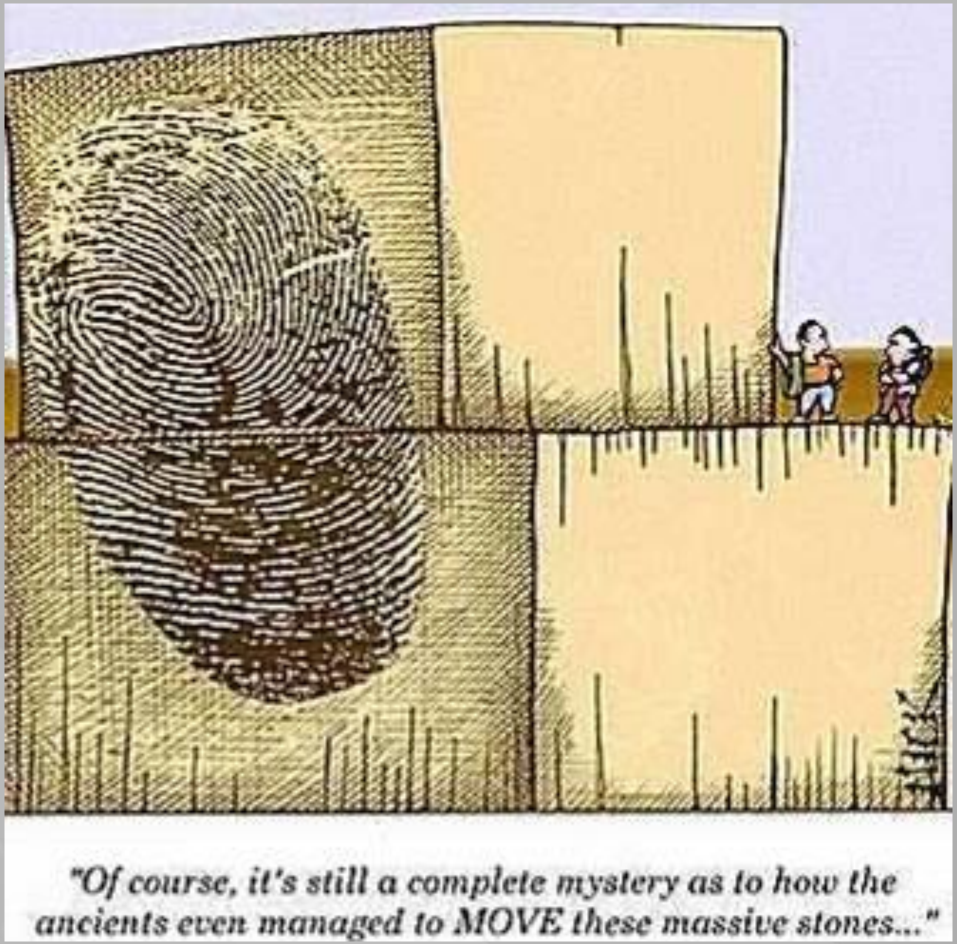
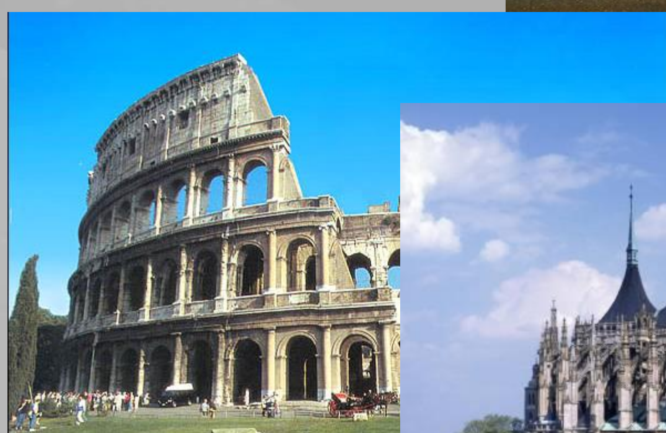
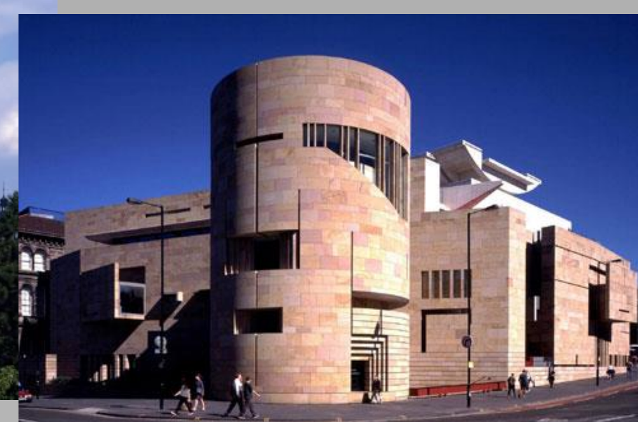
Building stone



Building stone





Building stone

- **all kinds of solid rocks, which have suitable properties to be used in construction works**
- rocks must have certain physical and chemical properties based on their mineralogical and petrographic composition, structure, texture, secondary alterations, etc.

dimension stones > 125 mm

(x aggregates < 125 mm)

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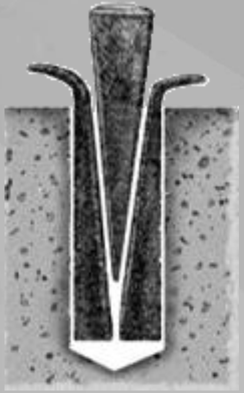
Some properties of common rocks

Type of rock	Porosity (%)	Density pcf (kg/m^3)	Compressive strength ksi (MPa)	Modulus of elasticity ksi (MPa) × 10^{-3}
Granite	0–2	165 (2650)	15–35 (103–241)	6–10 (41.3–68.9)
Limestone	0.5–30	168 (2700)	5–35 (34.4–241)	4–14 (27.6–96.5)
Marble	0–1.5	175 (2750)	10–30 (68.9–206.7)	4–14 (27.6–96.5)
Sandstone	1–20	160 (2580)	7–30 (48.2–206.7)	1–7.5 (6.9–51.7)
Slate	—	170 (2740)	—	—
Shale	2–30	140 (2255)	—	—

- **igneous**
  - R_c= 120- 400 MPa, ρ_v= 2500 – 3000 kg.m^{-3}
- **sedimentary**
  - R_c= 50 – 150 MPa, ρ_v= 2000 – 2800 kg.m^{-3}

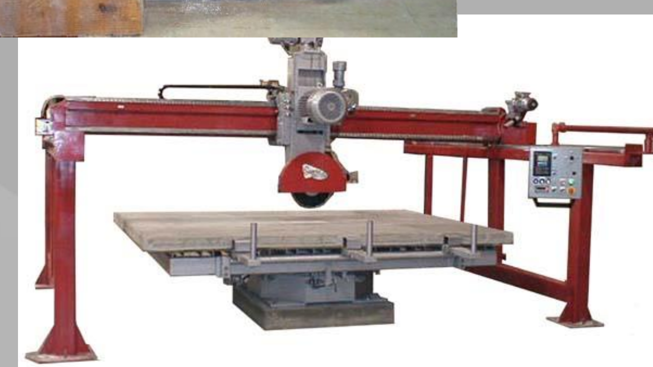
Stone extracting

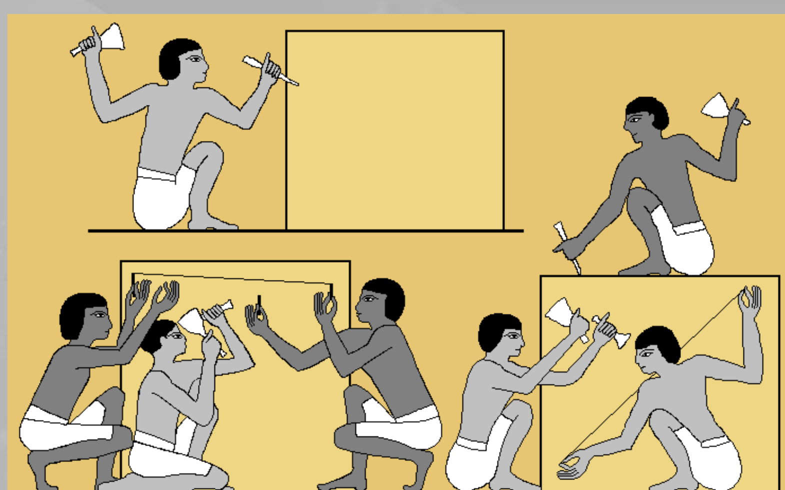
- **quarry**
  - **broaching** (channeling)
    - holes, wedges
  - **blasting**
    - explosives



Stoneworking

- cutting
- carving
- surface finishing





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Granit processing

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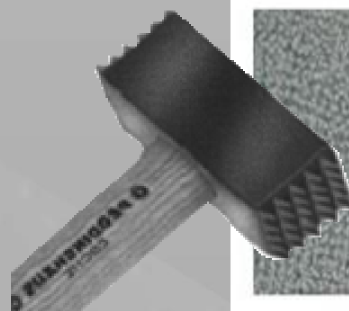
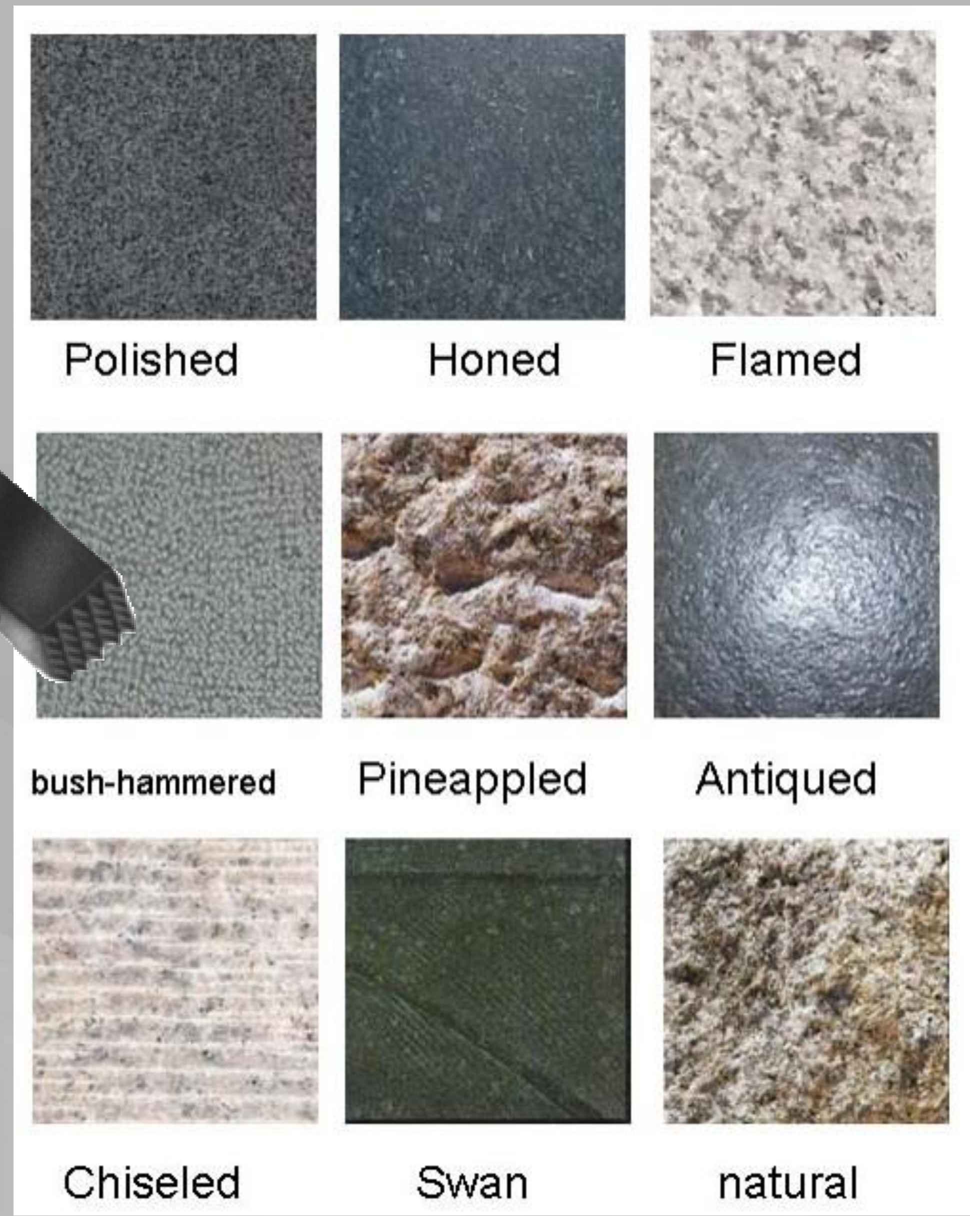
Surface finishes





Granite

Mechanical properties:

- high compressive strength
- hard surface
- difficult to work with
- can be polished

Appearance:

- medium to coarse texture
- pink to dark gray or even black
- small porosity

Use:

- external walls, flooring tiles, kerbs, paving stones, stairs

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Basalt

Mechanical properties:

- high compressive strength
- very hard surface
- difficult to work with

Appearance:

- fine grained
- black, dark gray, greenish black

Use:

- external walls, floors, cobblestones
- aggregates
- products from melted basalt

Sandstone




Mechanical properties:

- easy to work with
- only particularly resistant to weather

Appearance:

- sand grains (0.05-2mm) cemented together
- the color varies from red, green, **yellow**, gray and white

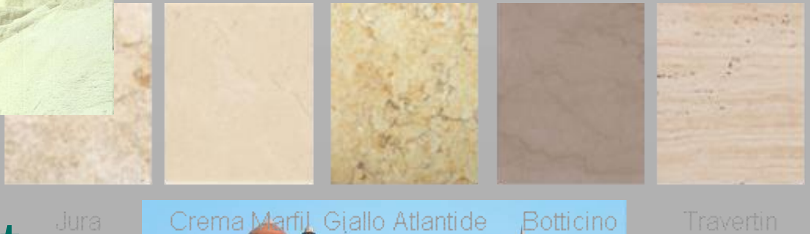
Use:

- decorative stones, flooring, paving, garden architecture

Limestone

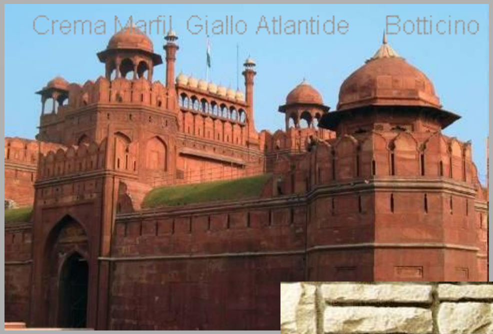
Mechanical properties:

- easy to work with
- soft
- acid sensitive
- low porosity



Appearance:

- often a sandy color but sometimes it can be gray, greenish, or blackish



Use:

- flooring, wall cladding
- raw material for cement, lime…

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Marble (recrystallized limestone)

Mechanical properties:

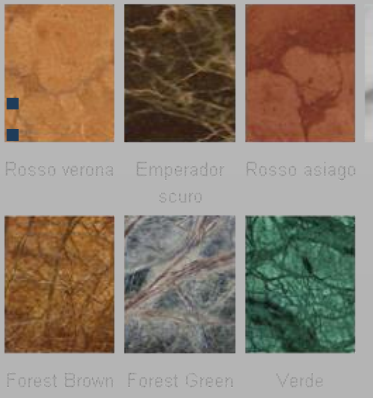
- easy to work with
- easy to polish
- not resistant to acids

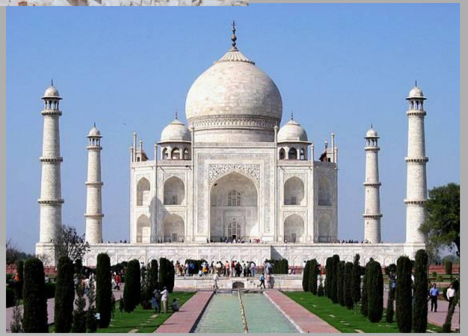
Appearance

- a wide variety of colors

Use:

- interior decoration, statues
- cladding, floors (interior)





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Slate

Mechanical properties:

- can be split into thin layers
- extremely low water absorption
- good weather resistance

Appearance:

- color mostly gray

Use:

- cladding, flooring - tiles
- roof tiles - slates

Dimension stone

- **natural stone or rock that has been selected and fabricated** (trimmed, cut, drilled, ground) **to specific sizes or shapes**

Types:

- **quarried (ruble) stone**

- **dressed stone**
  - rough stone that has to be adjusted to fit a shape

- **cut stone**

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Rubble stone

- broken stone, of irregular size, shape and texture
- scrap left over from quarrying and processing
- may be roughly shaped into blocks, but it is not finished
- rubble stone walls
- fill
- stepping stones
- cyclopean masonry

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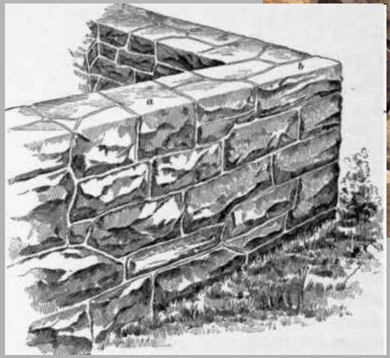
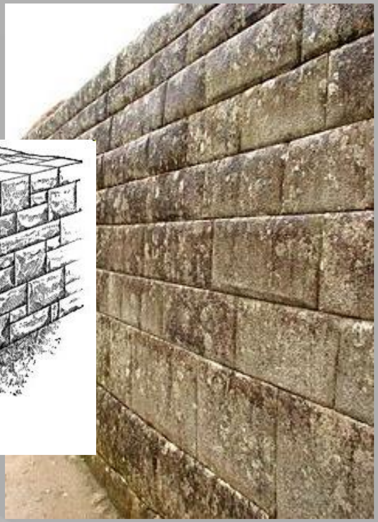
Stonemasonry

- **rubble masonry**
  - roughly dressed stones are laid in a mortar
  - quarried stone should be used



- **ashlar masonry**
  - stone masonry using cut stones
  - ashlar blocks
  - small ashlar



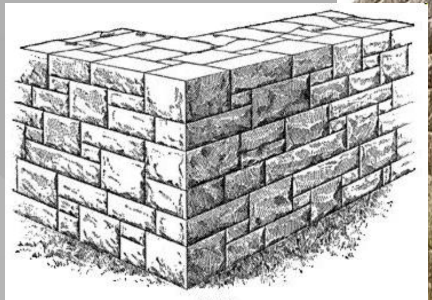


Fig. 28

Stonemasonry

- **stone veneer**
  - protective and decorative covering of walls
  - relatively small thickness and weight
- **slipform stonemasonry**
  - a reinforced concrete wall with stone facing in which stones and mortar are built up in courses within reusable slipforms

Another building stone types

- kerbs
- paving stones
  - cubes, cobblestones
- stone cladding
- stairs





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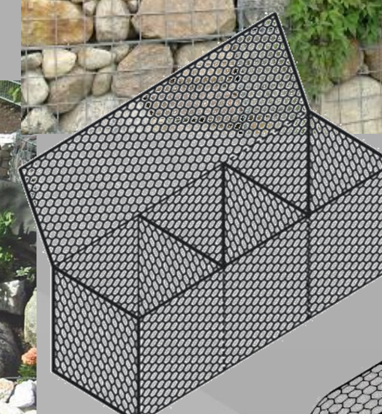
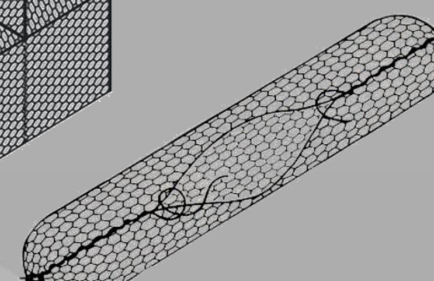
Gabion

- gabbia (it.) = big cage
- retaining walls
- slopes stabilization
- architectural elements



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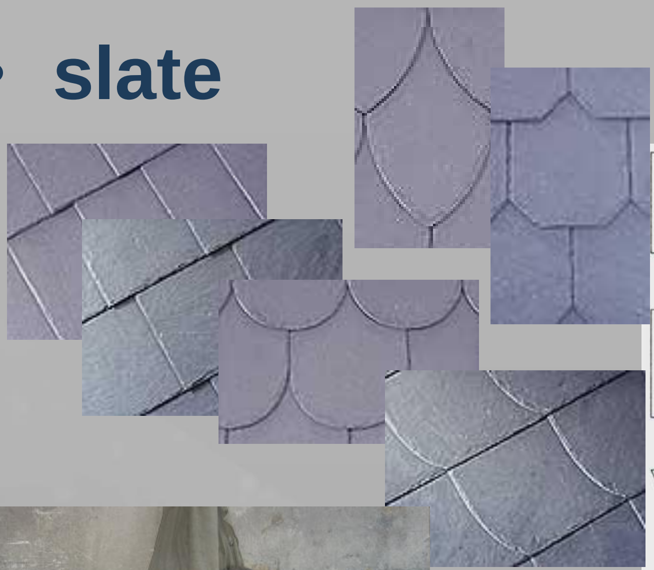
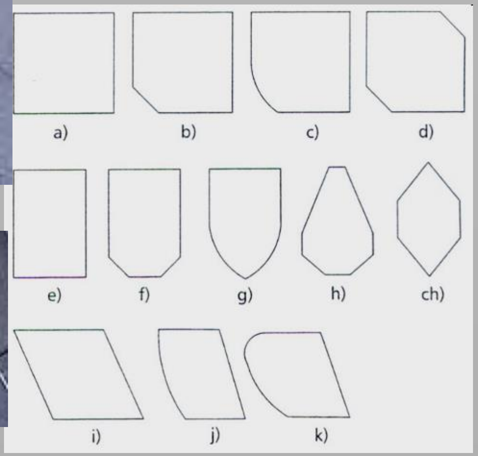
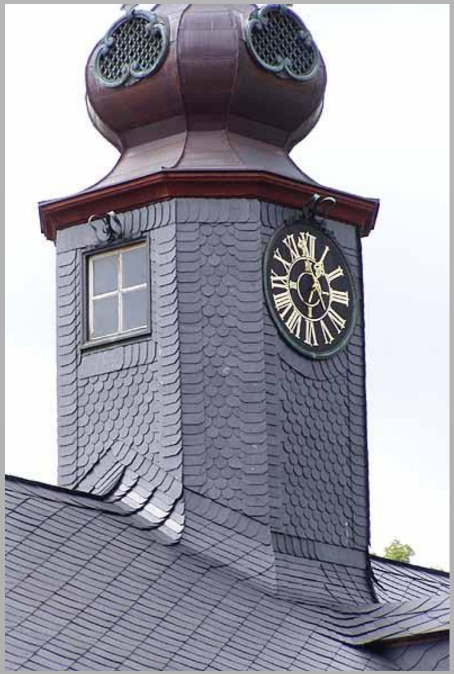
Stone roofing

- **slate**







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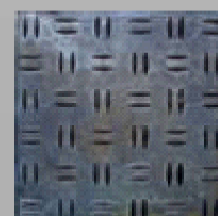
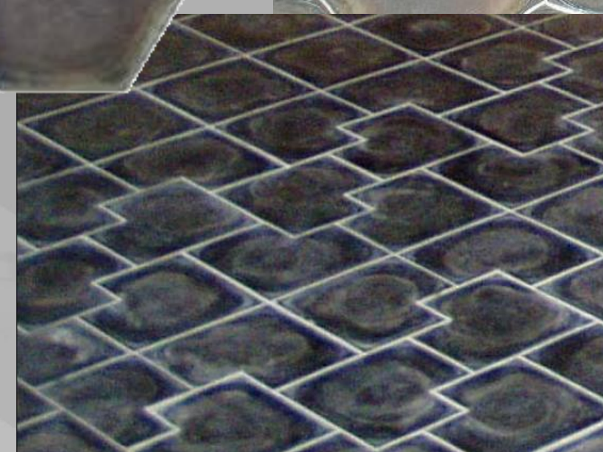
Artificial stone

- **binder** (white and/or grey cements or polymer resin), manufactured or natural **sands**, carefully selected **crushed stone** or well graded natural gravels and mineral coloring **pigments**
- manufactured s., cast stone, engineered stone

Cast basalt

- compressive strength 300 - 450 MPa
- hardness 8 (Mohs)
- outstanding wear and weather resistance





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Mineral fibers

EN 13162 – insulation material having a woolly consistency, manufactured from molten rock, slag or glass

- **boards or slabs** (λ= 0,035 - 0,045 W.m^{-1}.K^{-1}, ρ_V= 35 – 220 kg.m^{-3})
- **rolls** ($\lambda \cong$ 0,04 W.m^{-1}.K^{-1}, ρ_V= 70 kg.m^{-3})
- **batts, mats** ($\lambda \cong$ 0,04 W.m^{-1}.K^{-1}, ρ_V= 100-120 kg.m^{-3})
- **free wool**

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Mineral fibers use

- thermal insulations
- acoustic insulations
- fire proofing

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Asbestos

- **silicate minerals** (serpentine, amphibole, chrysotile, crocidolite) with long, (1:20) thin fibrous crystals
- fire resistant, strong, elastic
- **asbestos cement** (roofing, boards, pipes)
- **plasters, paints, sealants**

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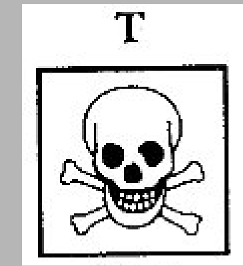
Asbestos



- prolonged inhalation of asbestos fibers can cause serious illnesses, (cancer - mesothelioma, asbestosis)

→ banned in EU

→ **difficult liquidation!**