Building Materials

Lecture 2

Building materials

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Basic physical properties

= related to **mass** and **volume** of the material

- **matrix density**
- **bulk density**
- **porosity**
- **granulometry**
- **fineness**

Mass

Choice of suitable scales:

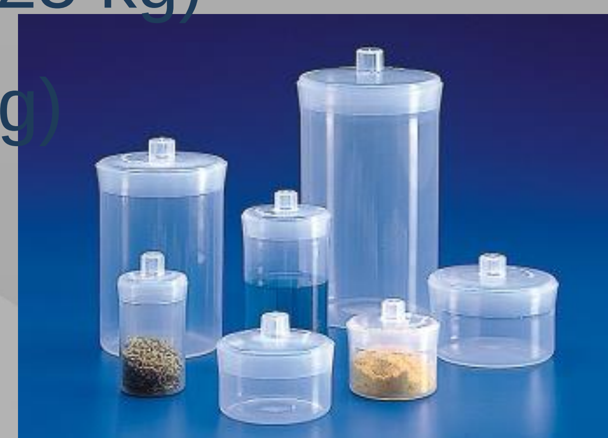
- **capacity** (max. range)
- **readability**

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Scales

Mechanical , digital

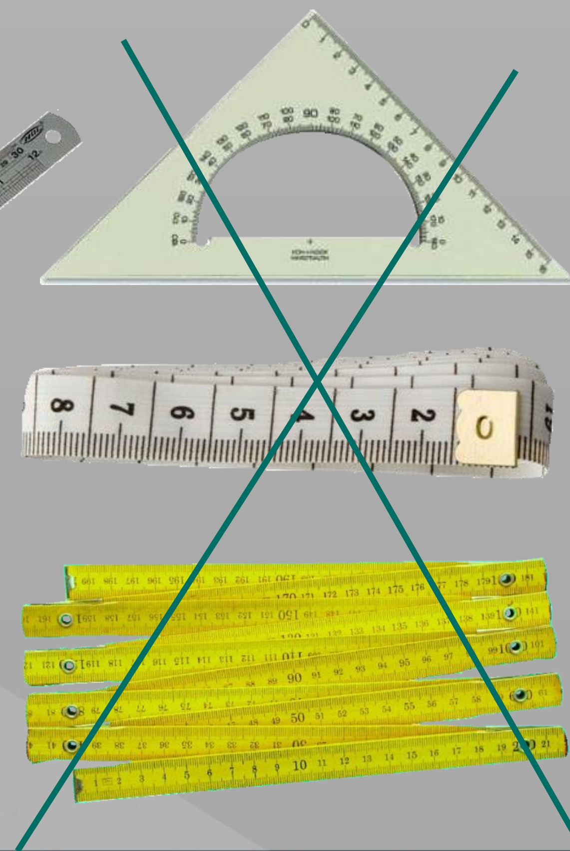
- **analytical** (readability 10^{-4} g, capacity to 200g)
- **milligram** (0,01 g)
- **laboratory** (0,1 - 0,2 g, 200 – 1000 g)
- **commercial** (2 - 5 g, 5 - 25 kg)
- **industrial** (hundreds of kg)

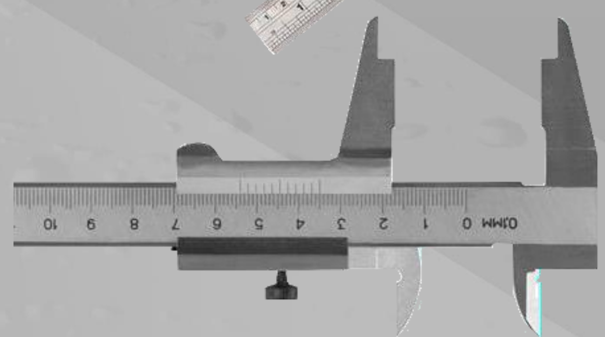


Size

Length measuring devices: calibrable

- **Steel rule**
- **Steel measuring tape**
- **Calliper**
- **Micrometer**
- **Sieves**





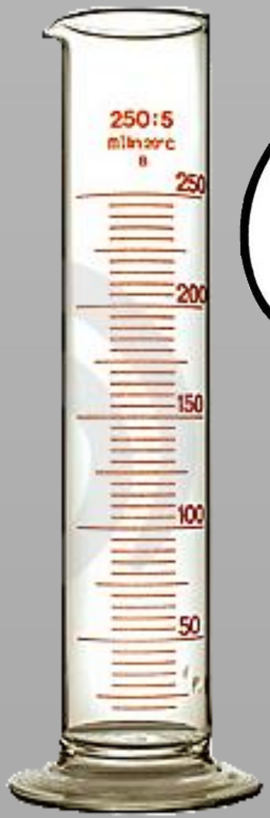
Volume

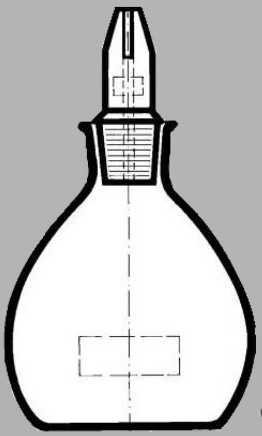
Solids:

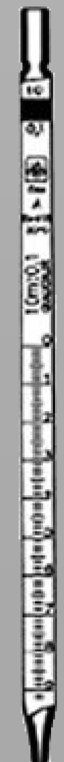
- **Calculation based on dimensions**
- **Immersion in liquid**
  - graduated cylinder
  - pycnometre
  - hydrostatic scales

Liquids:

  - volumetric flask
  - pipette
  - burette






Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Bulk density X Density

(matrix density)

$$\rho = \frac{m}{V}$$

[kg.m^{-3}]

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Bulk density

$$\rho_v = \frac{m}{V_s + V_p}$$

m… mass of material

V_s… volume of solid material

V_p… volume of voids in material

Density

(specific gravity)

$$\rho = \frac{m}{V_s}$$

m… mass of material

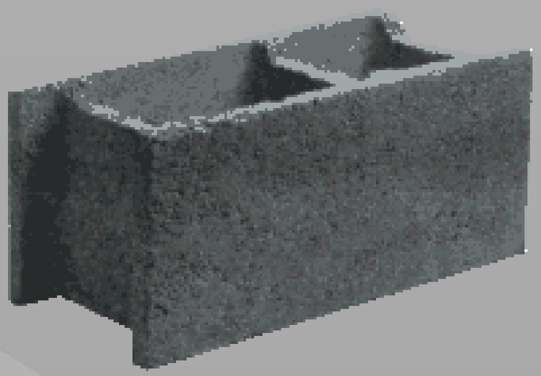
V_s… volume of solid material

Bulk density x Density

AAC
(aerated autoclaved concrete)

concrete

$\rho = 2400\ \mathrm{kg.m^{-3}}$ $\rho = 2500\ \mathrm{kg.m^{-3}}$



$\rho_V = 500\ \mathrm{kg.m^{-3}}$ $\rho_V = 2400\ \mathrm{kg.m^{-3}}$

Bulk density determination

$$\rho_V = \frac{m}{V_s + V_p}$$

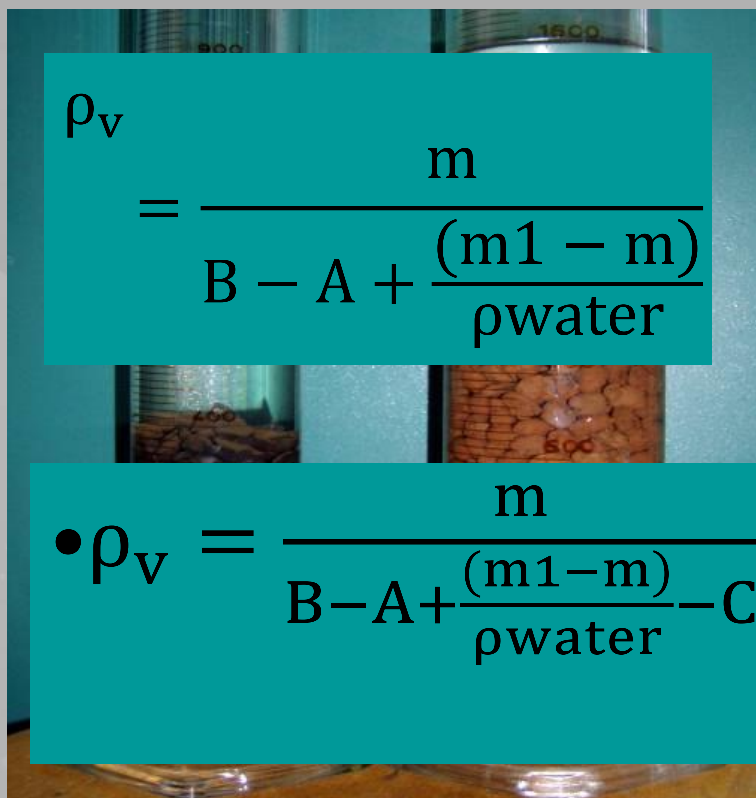
- mass **m** by weighing
- volume ($\mathbf{V_S+V_p}$)
  - counting from sizes (regular shape)
  - in graduated cylinder
  - by hydrostatical balance

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Bulk density determination:

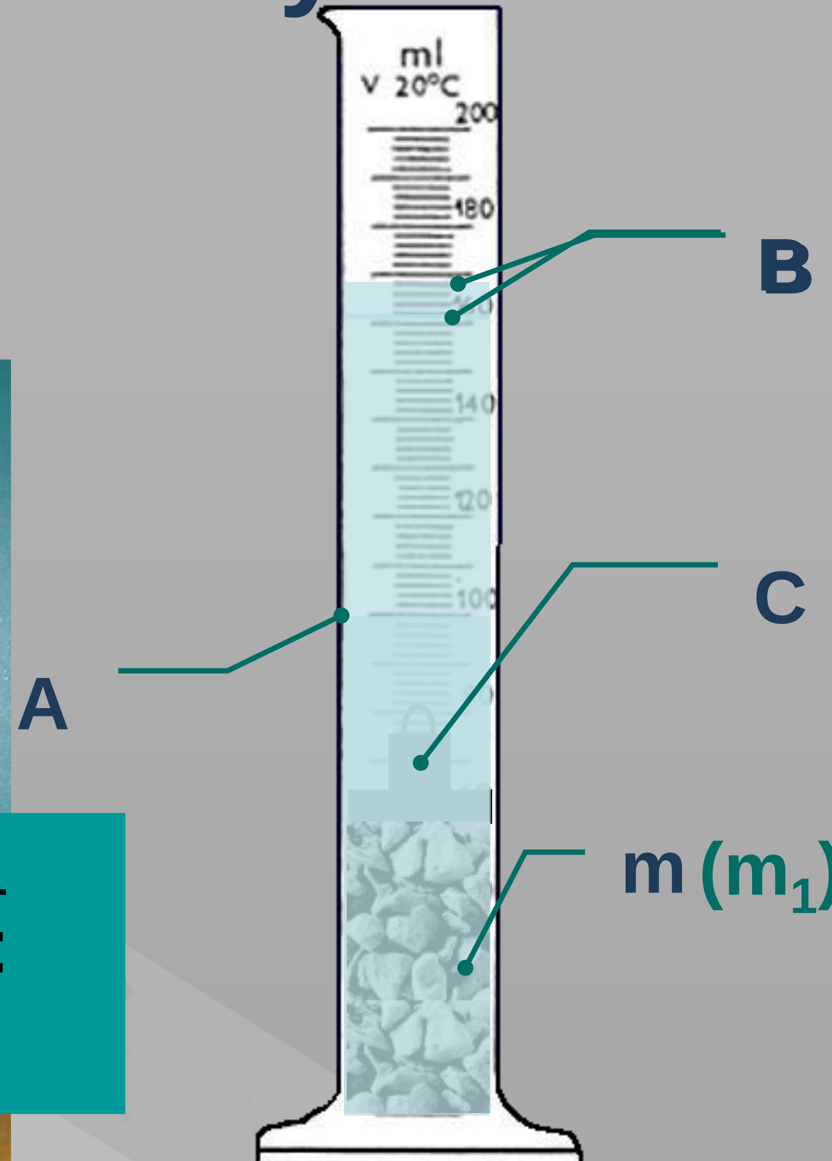
By graduated cylinder

$$\rho_v = \frac{m}{B - A}$$



$$\rho_v = \frac{m}{B - A + \frac{(m1 - m)}{\rho water}}$$

- $$\rho_v = \frac{m}{B - A + \frac{(m1 - m)}{\rho water} - C}$$



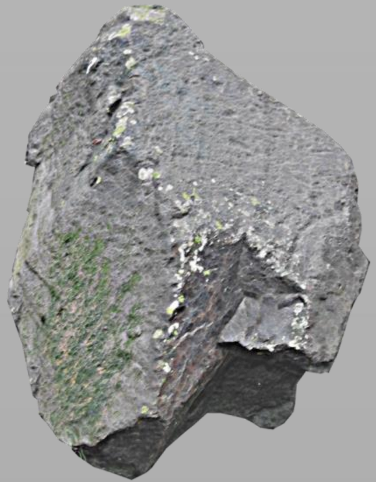
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

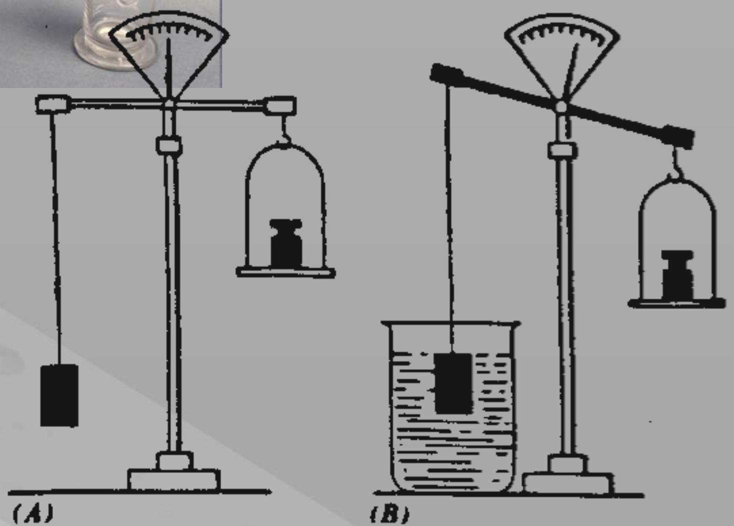
Building materials

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Bulk density determination:
By hydrostatical balance

- irregular shape → volume?

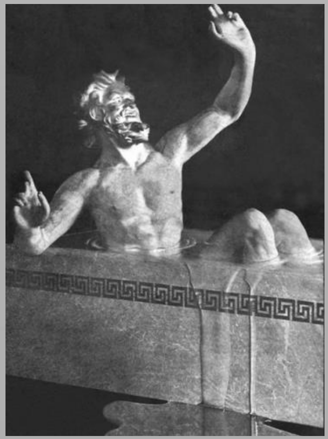




Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Bulk density determination:

By hydrostatical balance



Archimedes principle:

„Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.“

→ from that difference the volume of the displaced water can be count (its density is known)

→ mass of material, weighted under water is lower than that weighted in the air

$$\rho_{H_2O} = \frac{m}{V}$$

volume of displaced water = volume of material

Bulk density determination:

By hydrostatical balance

$$\rho_{H_2O} = \frac{m}{V} \rightarrow$$

$$V = V_{H_2O} = \frac{m}{\rho_{H_2O}}$$

$$V = \frac{m_{in\,air} - m_{in\,water}}{\rho_{H_2O}}$$

$$\rho_V = \frac{m_{in\,air}}{V} = \frac{m_{in\,air}}{m_{in\,air} - m_{in\,water}} \rho_{H_2O}$$

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Bulk density determination:

By hydrostatical balance

$$\rho_a = \rho_W \frac{M_4}{M_1 - (M_2 - M_3)}$$

- **M_1** mass of the sample in the air
  - *wet and dryed on the surface (aggregates)*
  - *dry (concrete)*
- **M_2** mass of the sample incl. the basket under water

- **M_3** mass of the empty basket under water
- **M_4** mass of dry sample
- ρ_w water density at testing temperature

Bulk density of fresh concrete

- EN 12350-6:2009 Testing fresh concrete. Density

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Bulk density of building materials

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

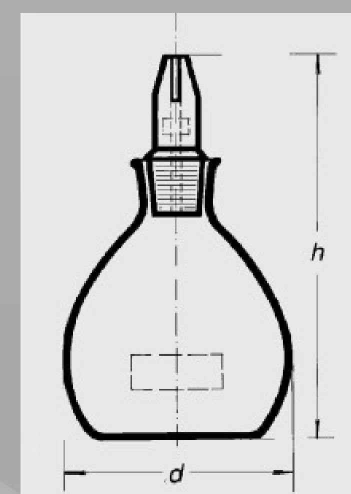
Specific gravity (matrix density) determination

$$\rho = \frac{m}{V_s}$$

- **Mass m** by weighing
- **Volume V_s by pycnometer**
  - material have to be finely grounded to avoid pores !

Pycnometer

- (glass) bottle with a close-fitting stopper with a capillary tube through it allowing excess liquid to escape
- the volume of the liquid in the pycnometer is always the same
- allows repeated obtaining a given volume of liquid with a high accuracy



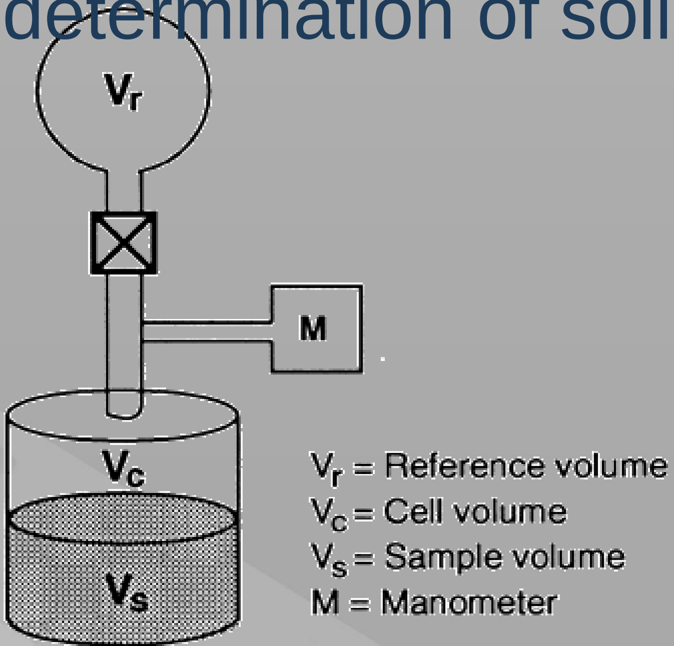
Determination of density by pycnometric method

m_1 m_2 m_3 m_4

$$\rho = \frac{(m_2 - m_1) \times \rho_k}{(m_2 - m_1) + m_4 - m_3}$$

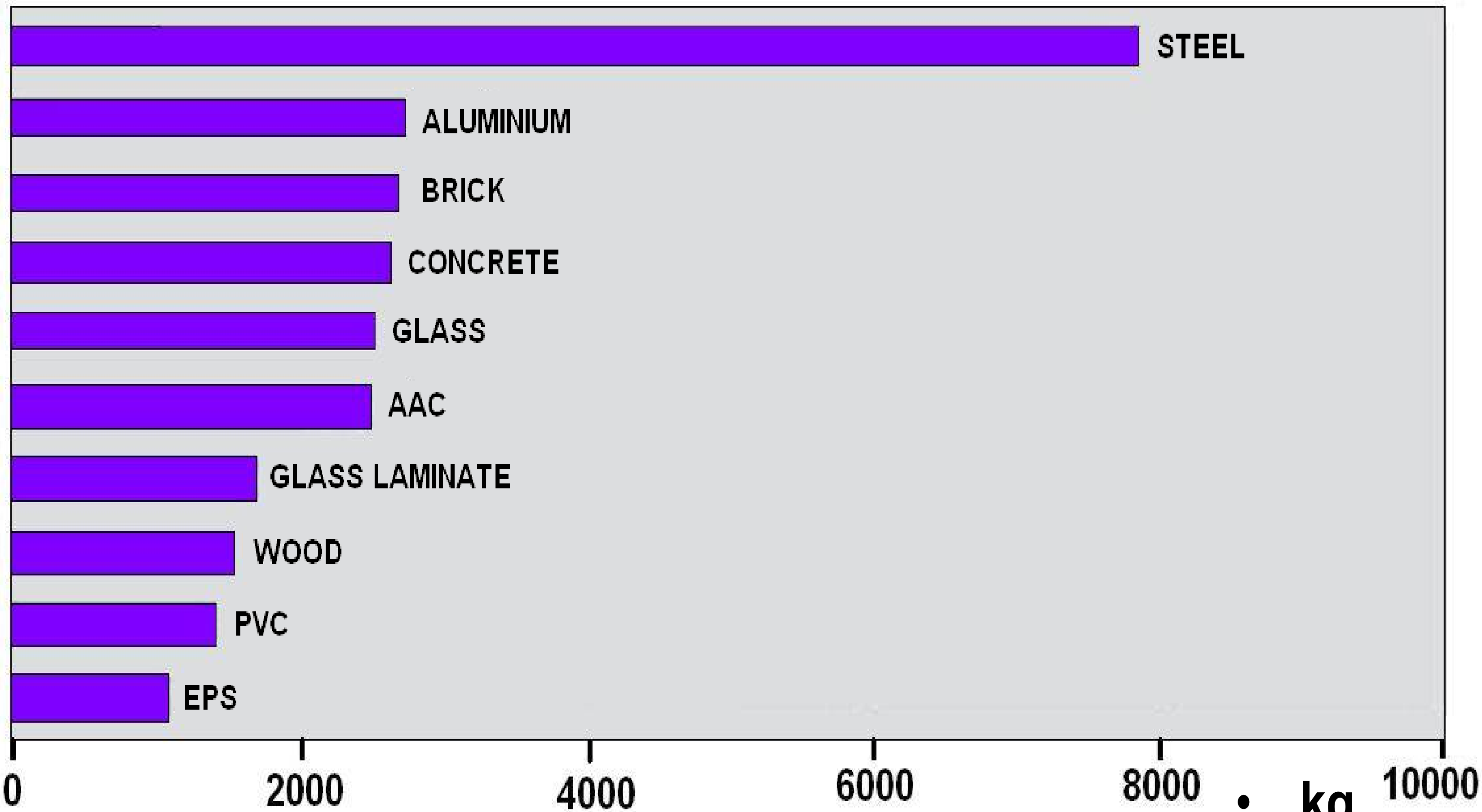
Helium pycnometer

- the size of helium atoms is very small
- helium, under precisely-known pressure, is used to fill small voids within a specimen
- the volume change of helium in a constant volume chamber allows determination of solid volume



Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Density of building materials



- kg. m^{-3}

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Porosity

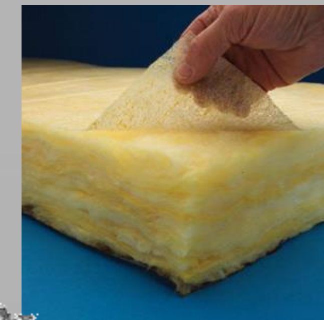
- **ratio of the volume of the pores to the total volume of the material**

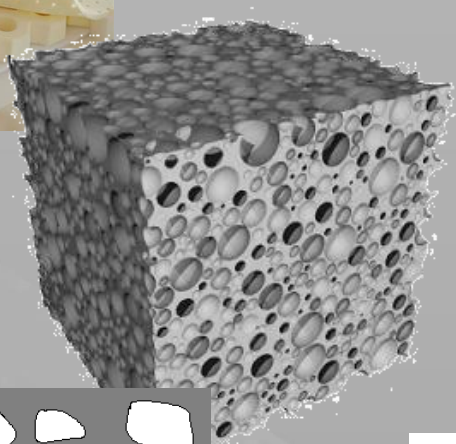
$$p = 1 - \frac{V_S}{V} = 1 - \frac{\rho_v}{\rho}.(100)$$

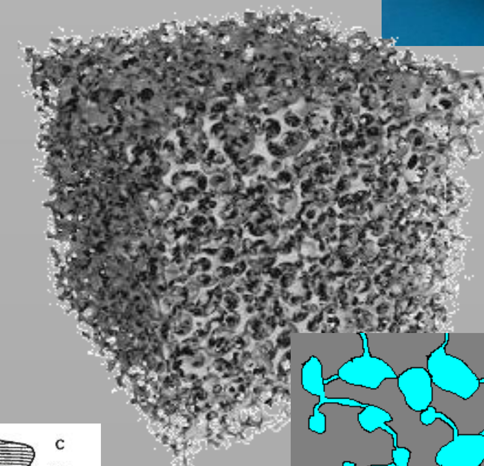
- usually expressed as a percentage

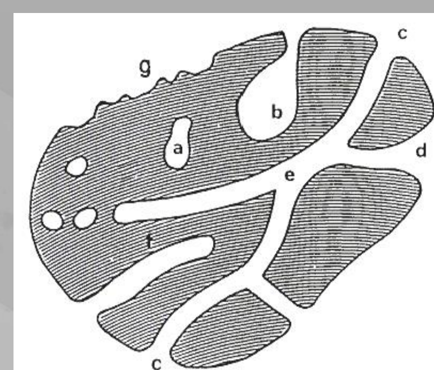
Types of pores

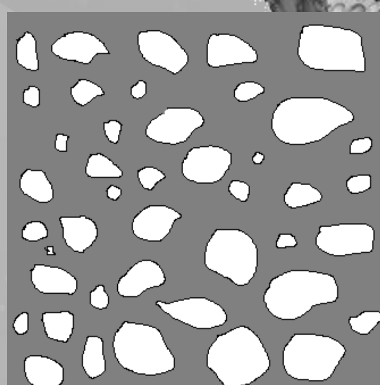
- closed
- open

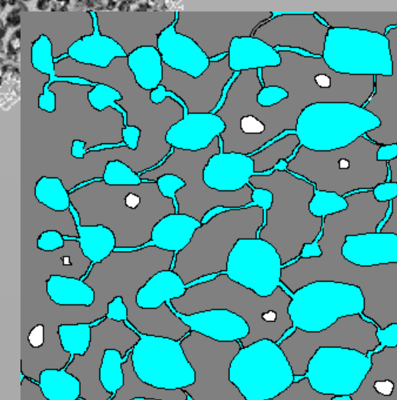












$$p = p_{closed} + p_{open}$$

Properties related to porosity

- Water absorption → frost resistance
- Gas and liquid transport
- Acoustic absorptivity
- Thermal conductivity
- Mechanical properties - strength

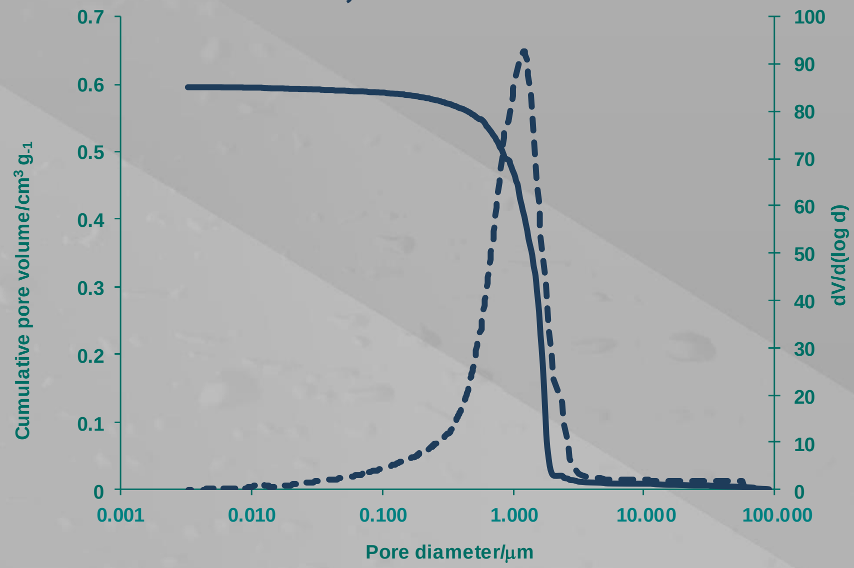
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Pore size distribution

Mercury porosimetry

- the intrusion of a mercury at high pressure into a pores
- the pressure needed to fill the pores increases with decreasing pore diameters
- 400 MPa → Ø1,5 nm



Building materials

Department of Materials Engineering and Chemistry

Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

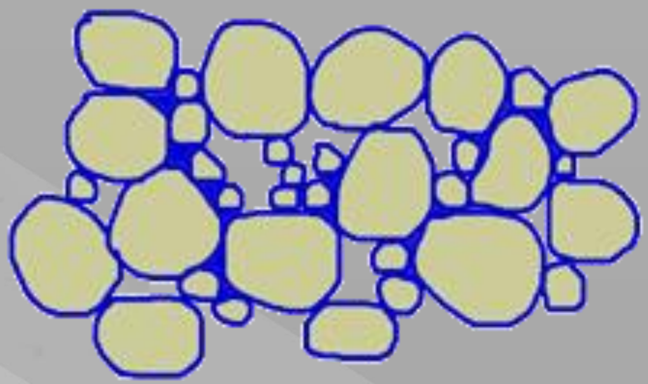
Properties of loose materials

Loose material = solid material divided into many small particles

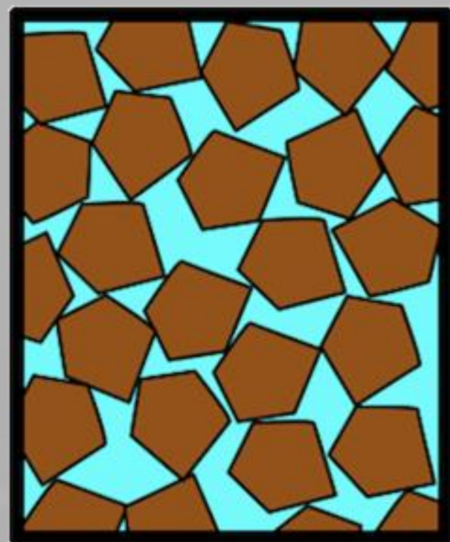
- an assembly of solid particles that is large enough for the statistical mean of any property to be independent of the number of particles

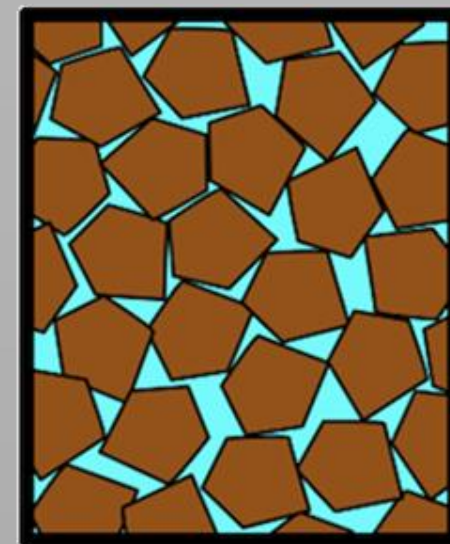
Void ratio

- volume of voids (between particles of a loose material) and the total volume
- the amount of void space depends on gradation, particle shape and texture, and compactness (rate of compaction)



Compacting





Uncompacted material - the volume of voids in an uncompacted (unconsolidated) material

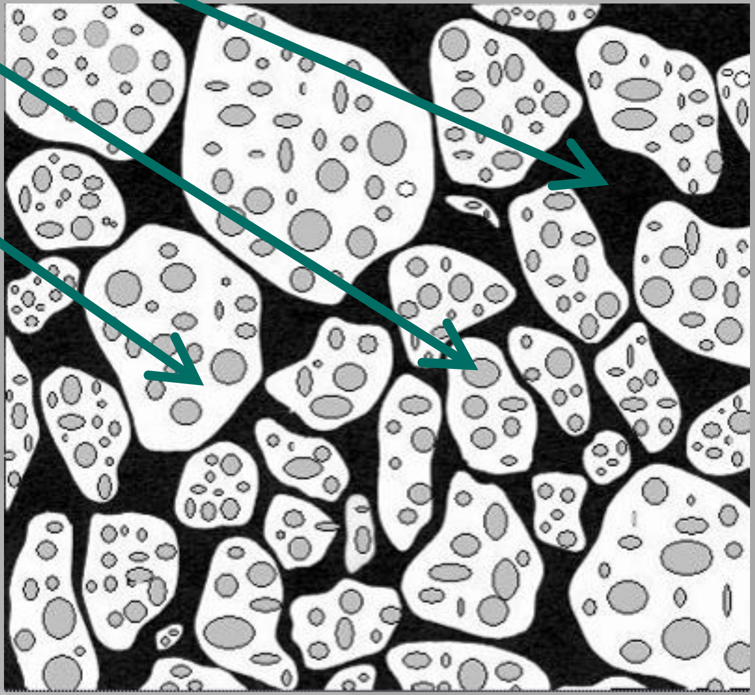
$>$

Compacted material - the volume of voids in a fully/partially compacted (f/p consolidated) material

Loose (bulk) **density**

$$\rho_L = \frac{m}{V_S + V_P + V_V}$$

- **in the uncompacted state**
- **in the consolidated state** (compacted)



Loose (bulk) **density determination**

- Standard container (volume according maximum particle size) + tamping rod

Procedure:

- **Loose weight:**
  - fill the container
  - struck off the surplus
- **Compact weight:**
  - fill the container in equal layers
  - each layer being subjected to strokes with the tamping rod
  - struck off the surplus

Aggregates

- granular material used in construction
- inorganic rocklike material
- various sizes and shapes
- particle size < 125 mm

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Size, gradation

Gradation = the particle size distribution

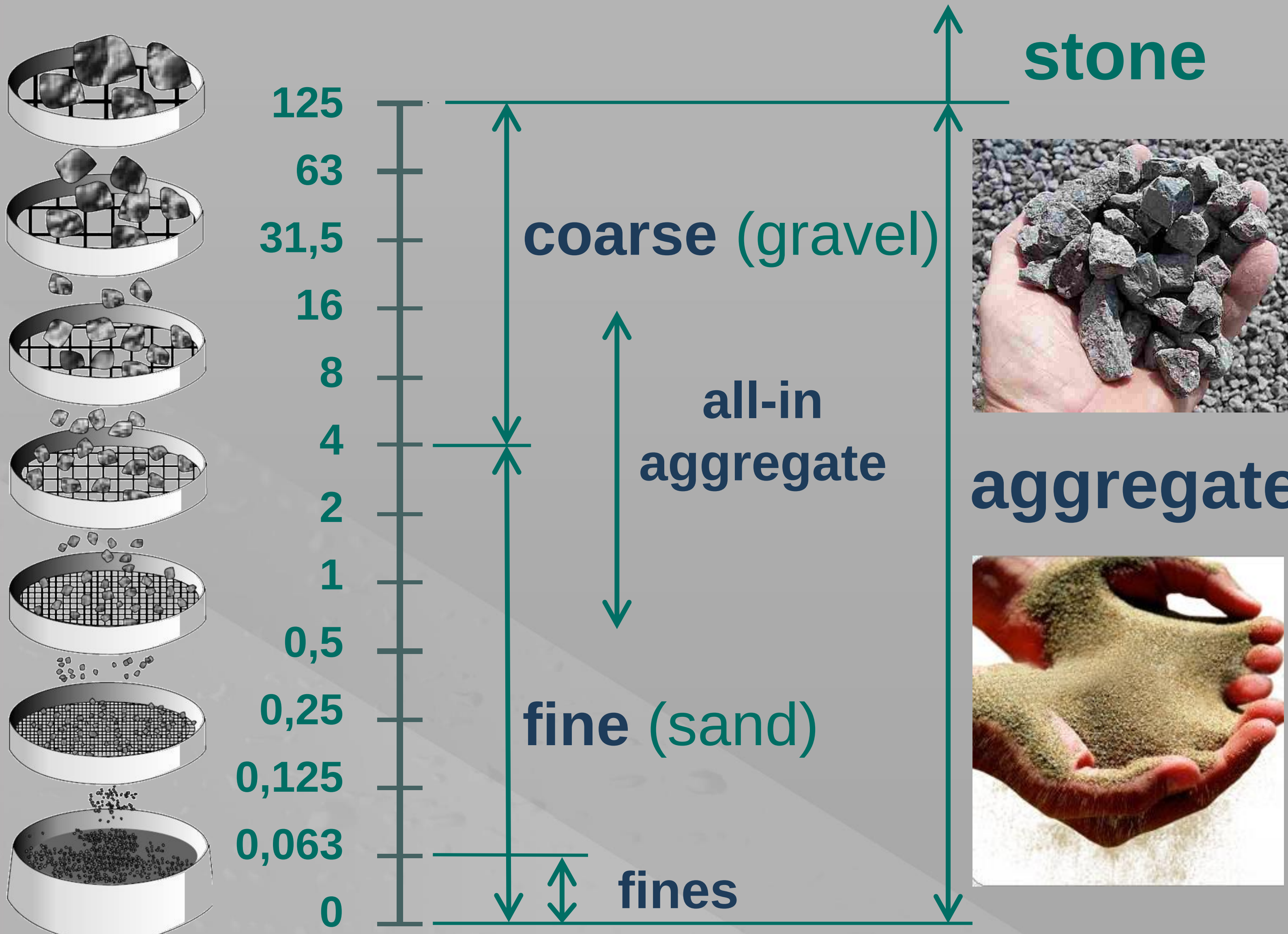
- amount of various particle sizes present in an aggregate
  - determined by sieve analysis
  - expressed as the percentage by mass passing a specified set of sieves

Standard sieves (EN 933-2)

125 mm
63 mm
31,5 mm
16 mm
8 mm
4 mm
2 mm
1mm
0,500 mm
0250 mm
0,125 mm
0,063 mm

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Type of aggregates according size



Building materials

Department of Materials Engineering and Chemistry

Faculty of Civil Engineering

Sieve analysis

- dividing up a material into size fractions by passing it through sieves with decreasing apertures

Aggregate size (fraction) (EN 933-1)

- designation of aggregate in terms of **lower** (d) and **upper** (D) sieve sizes expressed as d/D*
  - 16/64 aggregate will be that aggregate which passes the 64 mm sieve and is retained on the 16 mm sieve

* this designation accepts the presence of some particles which are retained on the upper sieve (**oversize**) and some which pass the lower sieve (**undersize**)

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Sieve analysis - definitions

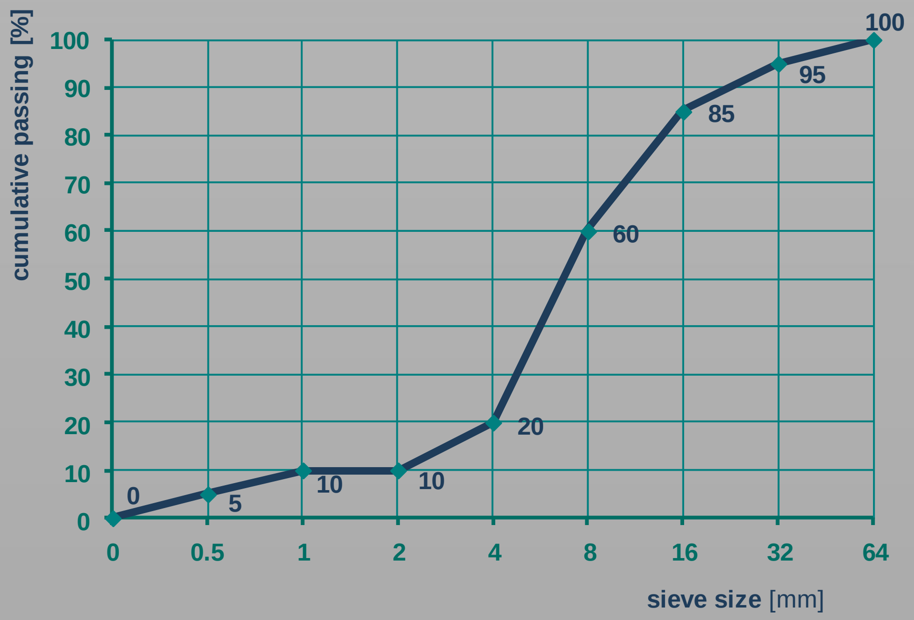
- **Individual retained** – the mass or percentage retained on one sieve after test
- **Cumulative retained** – sum of the mass or percentages retained on the sieve and on all coarser sieves

- **Cumulative passing** – sum of the mass or percentage passing the sieve (e.g. sum of the retained on all finer sieves and pan)

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Particle size distribution curve

- graphical listing of the amount of particles according to particle size ranges



- continuous line
  - axe X – **sieve size** (particle size)
  - axe Y – **cumulative passing** (percent passing by weight)

Example:

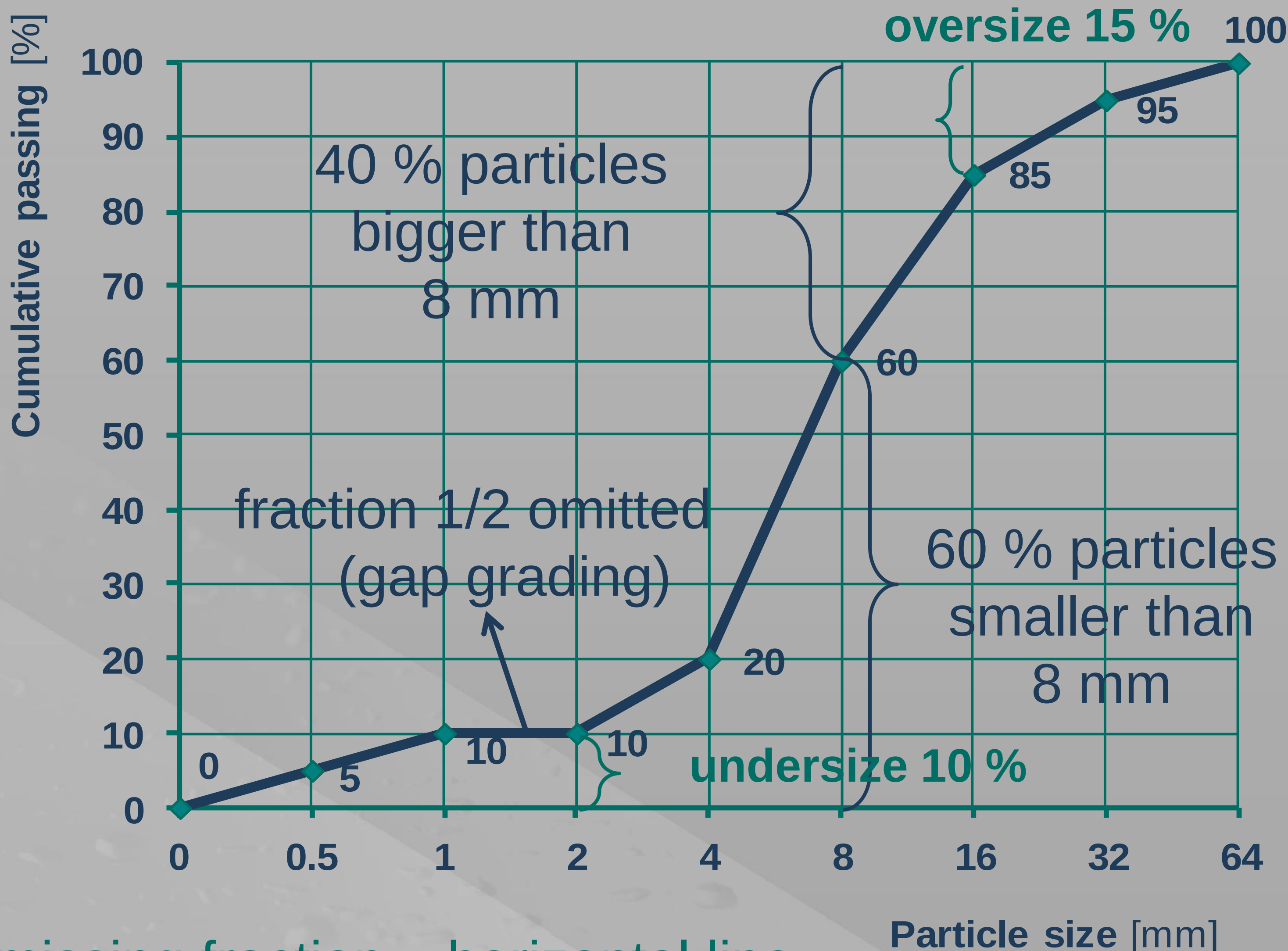
Aggregate, fraction **2/16** - 1000 g

- After sieve analysis these retained were obtained:

Sieve aperture size	Individual retained		Cumulative retained	Cumul. passing
	g	%	%	%
64	0	0	0	100
32	50	5	5	95
16	100	10	15	85
8	250	25	40	60
4	400	40	80	20
2	100	10	90	10
1	0	0	90	10
0,5	50	5	95	5
< 0,5 (pan)	50	5	100	0

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Particle size distribution curve

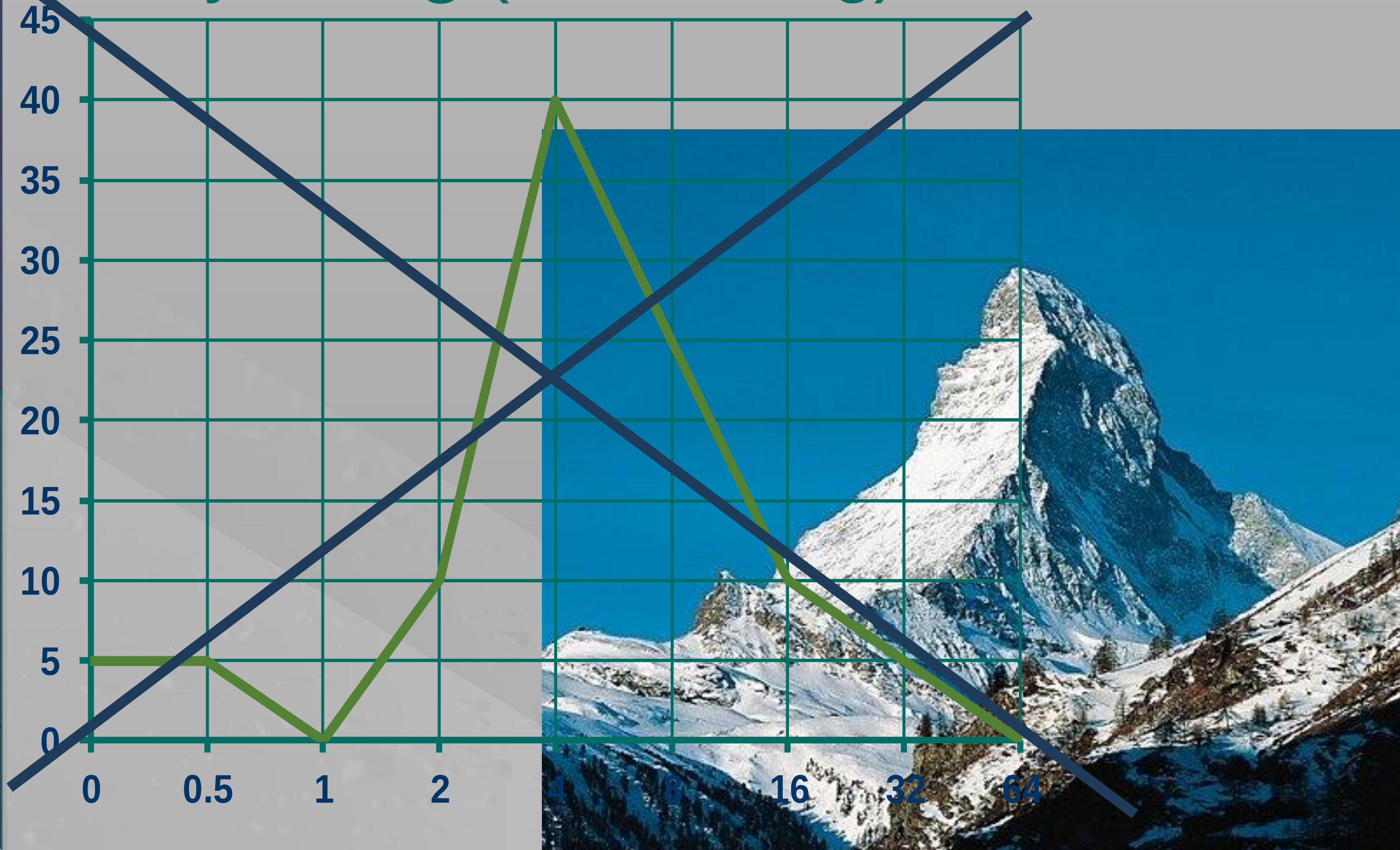


- missing fraction – horizontal line
- vertical line – never!

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Particle size distribution curve

- only **rising** (decreasing) character



Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

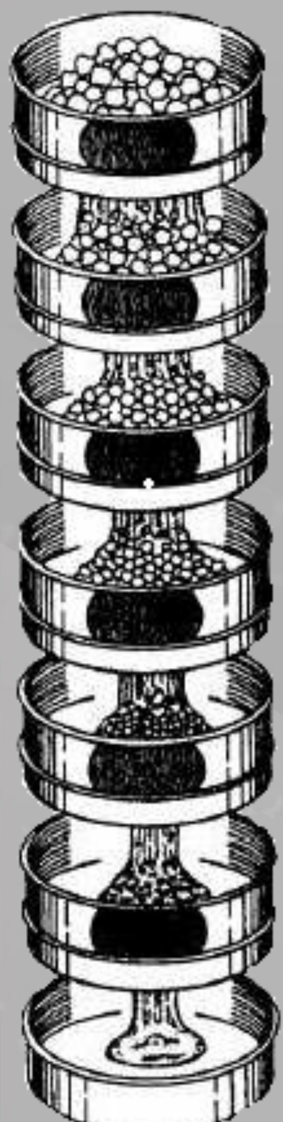
Fineness modulus

- to determining the degree of uniformity of the aggregate gradation
- **single number**
- obtained by adding the total percentages of material in a sample that are coarser than each of a specified series of sieves (cumulative percentages retained) and dividing the sum by 100.

$$\mathrm{FM} = \frac{\sum \text{cumulative retained on specified sieves } [\%]}{100\ \%}$$

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

$$FM = \frac{\sum \text{cumulative retained on specified sieves [\%]}}{100\ \%}$$



Z_{16}	Z_{16}
Z_{8}	+ $Z_{16} + Z_8$
Z_{4}	+ $Z_{16} + Z_8 + Z_4$
Z_{2}	+ $Z_{16} + Z_8 + Z_4 + Z_2$
Z_{1}	+ $Z_{16} + Z_8 + Z_4 + Z_2 + Z_1$
$Z_{0,5}$	+ $Z_{16} + Z_8 + Z_4 + Z_2 + Z_1 + Z_{0,5}$
Z_{0}	+ $Z_{16} + Z_8 + Z_4 + Z_2 + Z_1 + Z_{0,5} + Z_0$

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Building materials

Fineness modulus
EN 12620

Specified sieves: 4 - 2 - 1- 0,5 - 0,25 - 0,125

$$\mathbf{FM} = \frac{\sum[(\rangle \mathbf{4}) + (\rangle \mathbf{2}) + (\rangle \mathbf{1}) + (\rangle \mathbf{0,5}) + (\rangle \mathbf{0,25}) + (\rangle \mathbf{0,125})]}{\mathbf{100}}$$

$$1 < FM < 6$$

- the bigger FM is, the coarser is aggregate

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Fines

= particle size fraction which passes the 0.063 mm sieve

- several **methods for determining** (washing, sand equivalent test, methylene blue test, air jet sieving)
- maximum value:
  - fine aggregate $<$ **3 %**
  - coarse aggregate $<$ **1.5 %**
- higher content of fines:
  - higher consumption of cement
  - lower strength

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

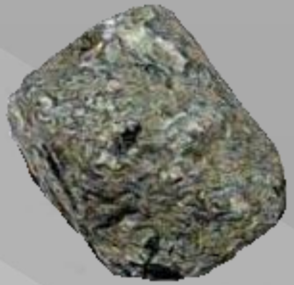
Shape and texture of particles

Particles:

- **shape** – rounded, angular, elongated, flat



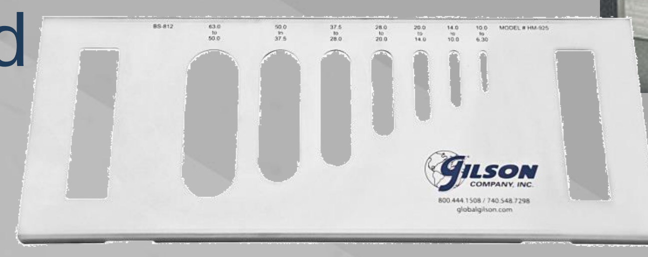

- **surface** – smooth, rough (abraded)

Flakiness index

(EN 933-3)

- particles are **flaky (flat)** when their thickness is less than 0.6 of their mean size
- special sieves with elongated apertures
- **the flakiness index - ** the weight of the flakey aggregate as a percentage of the aggregate tested



Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

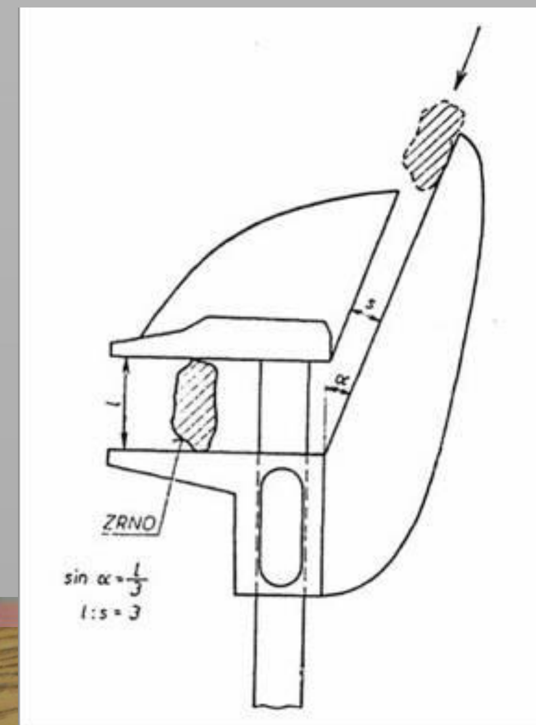
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Shape index
(EN 933-4)

- a ratio between the weight of particles with L/E > 3 and weight of all measured particles in percents.
  - **shape ratio L/E** – the length L and the thickness E of each particle
  - **L/E > 3** – non-cubic particles

- elongation index

Shape ratio L/E



Building materials

Department of Materials Engineering and Chemistry

Faculty of Civil Engineering

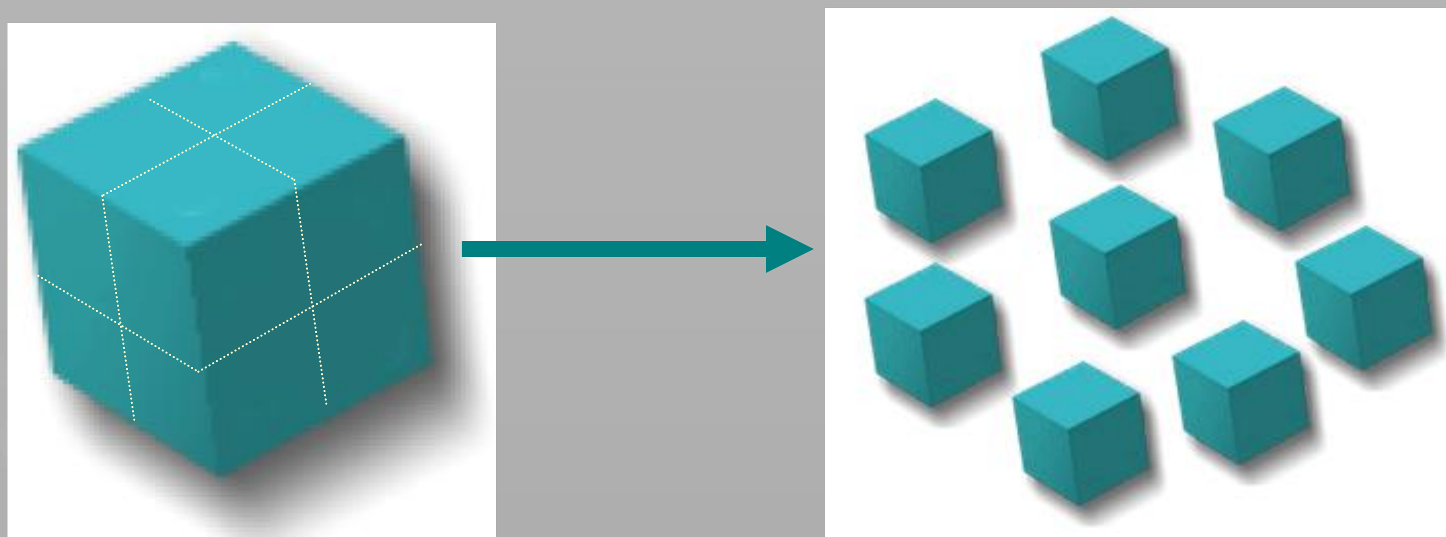
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Specific surface

- **describes fineness**
- **total surface area per unit of mass**
- units: **m^2/ kg** (cm^2/g)
- the higher the specific surface is, the finer material will be

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Specific surface



cube 2 x 2 x 2 cm

each face is 4 cm^2

6 faces x 4 m^2 = 24 cm^2

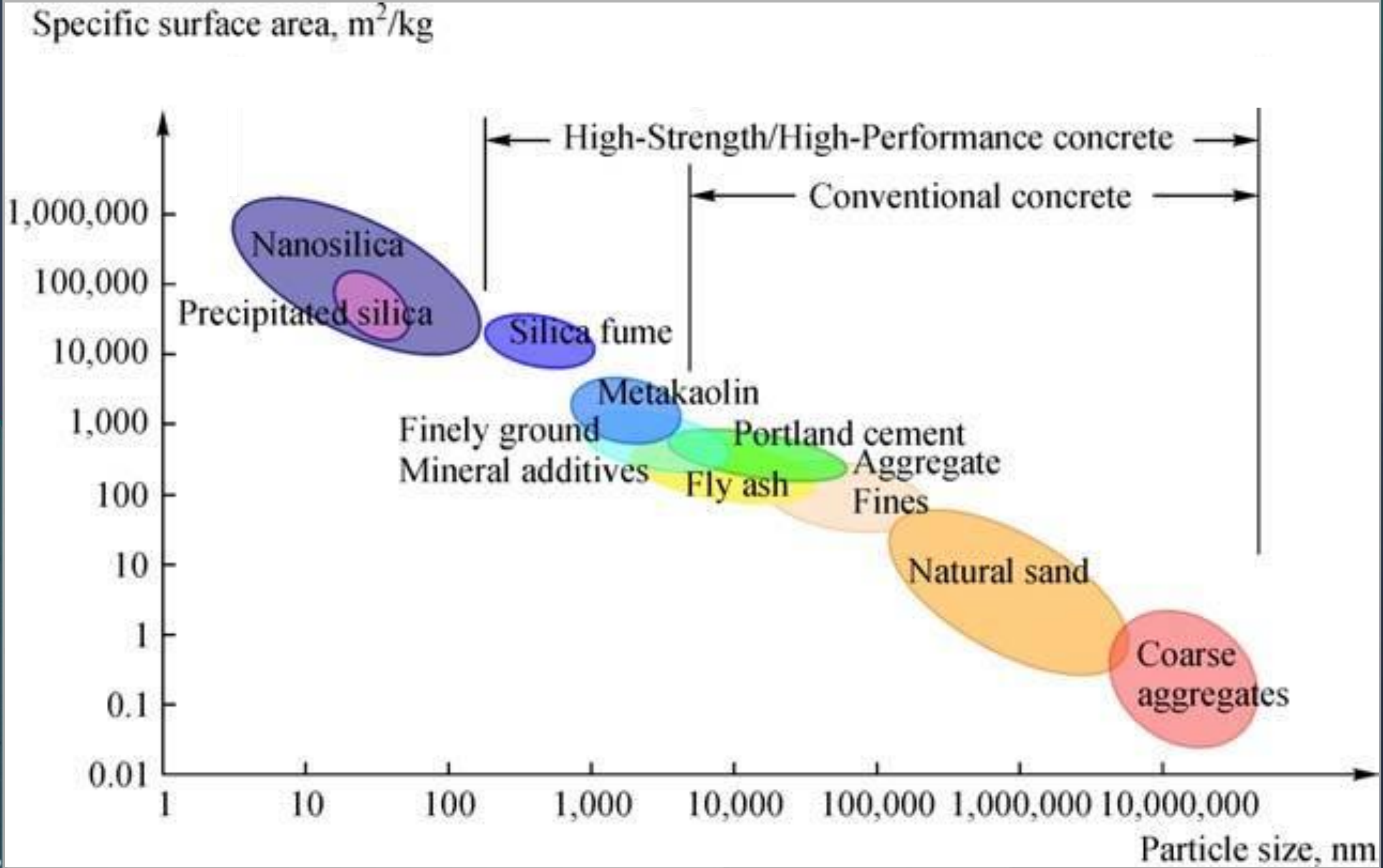
8 cubes 1 x 1 x 1 cm

each face is 1 cm^2

6 faces x 1m^2 x 8 cubes = 48 cm^2

- **if each of the resulting cubes was divided similarly, the surface area would increase 16 times more**

Specific surface of some materials



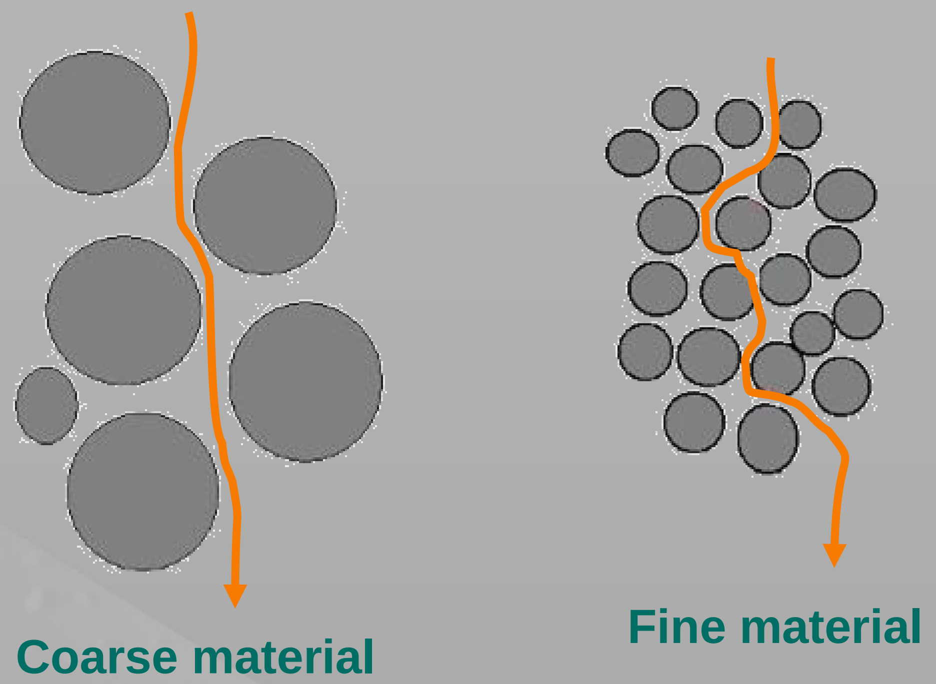
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Specific surface determination

- (sieving)
- gas permeability
  - **air permeability** (Blaine method)
  - used for cement
- gas adsorption
  - „BET“ method
  - **the physical adsorption of gas molecules on a solid surface**

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Air permeability method



- the specific surface is derived from the resistance to flow of air through a porous bed of the powder

Blain apparatus

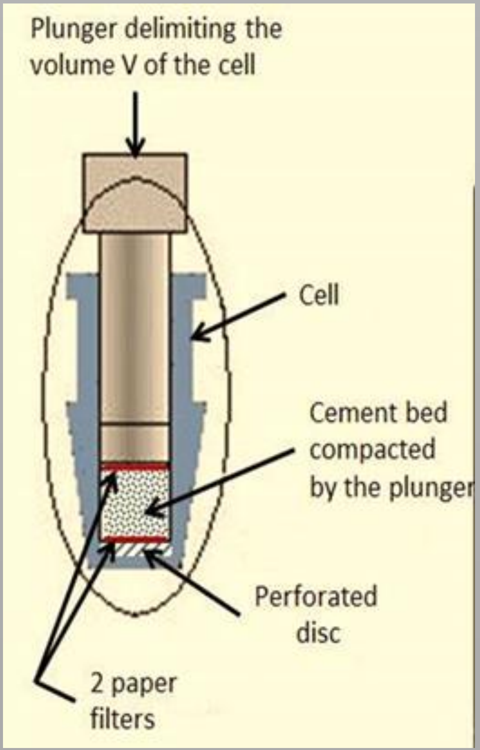
Blain apparatus

Ermittlung der spezifischen Oberfläche von Zement

Determining the specific surface area of cement

Specific surface calculation

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



- **K** apparatus constant
- **e** porosity of the bed (usually e = 0,500)
- **t** measured time [s]
- **ρ** cement density [g.cm^{-3}]
- **η** air viscosity at the test temperature [Pa.s]

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Building materials

Department of Materials Engineering and Chemistry

Faculty of Civil Engineering

Apparatus calibration

- apparatus must be calibrated, using a known standard material

$$K = S_0 \times \rho_0 \times \frac{(1-e)}{\sqrt{e^3}} \times \frac{\sqrt{0{,}1\eta_0}}{\sqrt{t_0}}$$

- **S_0** specific surface of the reference cement [$cm^2.g^{-1}$]
- **ρ_0** density of the reference cement [$g.cm^{-3}$]
- **t_0** measured time [s]
- **η_0** air viscosity at the test temperature [Pa.s]

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Fineness of grinding

- cements and similar materials
- described by the specific surface
- finer cement offers a greater surface area for hydration and hence faster the development of strength
- specific surface of common cements:

250 – 350 m^2/ kg

(2500 - 3500 cm^2/g)

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Mechanical properties

Building materials
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

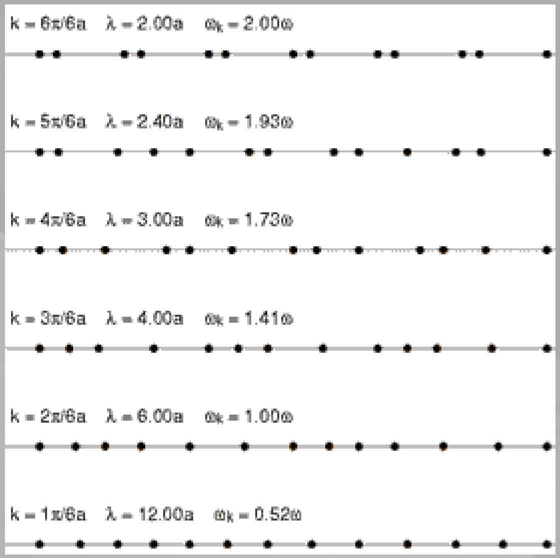
Building materials

Department of Materials Engineering and Chemistry

Faculty of Civil Engineering

Solid materials

- structural rigidity
- resistance to changes of shape or volume
- atoms are tightly bound to each other



Atomic vibration in crystalline solid

Mechanical properties

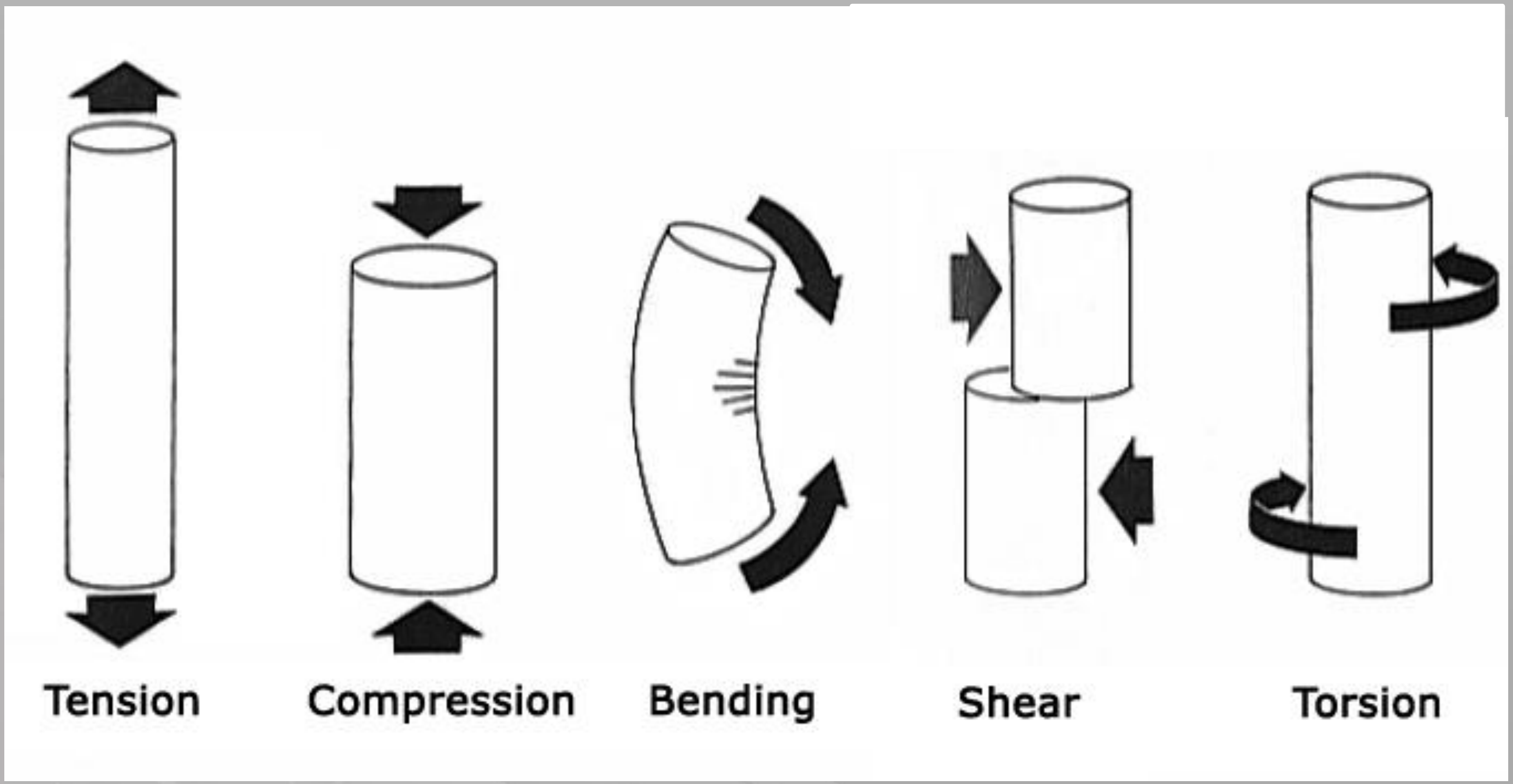
- material's behavior when force is applied
- characteristics such as the strength and resistance to deformation

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Mechanical properties

- **deformation properties** (before destruction)
- **strength properties** (at the moment of break)

Type of loading



Force x Stress

- **stress** is a measure of the **internal forces** which are a reaction to **external forces**

Force F ≠ stress σ

[N] ≠ [Pa]

≠

Isaac **Newton**

Blaise **Pascal**

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Compressive stress

$$\sigma = \frac{F}{S}$$

$$S = 0{,}005\ x\ 0{,}005 = 0{,}000025\ m^2$$

Units of stress

SI units: **Pascal**

$$Pa = \frac{N}{m^2}$$

$$MPa = \frac{N}{mm^2}$$

Imperial units: **pound-force per square inch**

$$psi = \frac{lbf}{in^2}$$

ksi = 1000 . psi

1 psi = 6 894,76 Pa

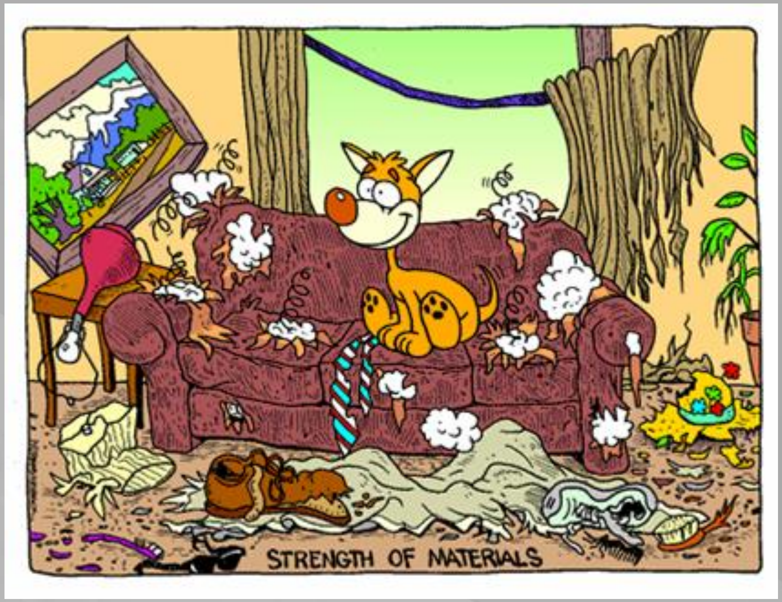
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Strength properties

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Strength

- ability to withstand an applied load without failure
- the **maximum stress** sustained by a material loaded to failure



Strength

According the way of obtaining:

- **theoretical** (structural)
- **technical**
- **statistical**

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

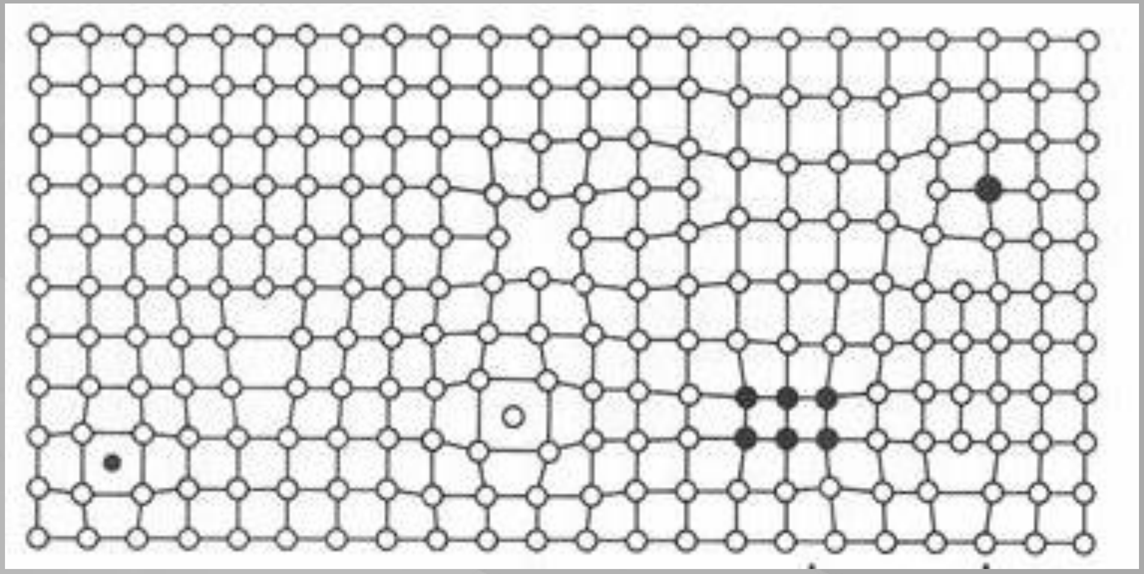
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Theoretical strength

- Counted from the number and strength of the bonds between atoms

X

- defects in the crystal lattice – real strength is distinctively lower (ca 1000x)



Technical strength

- **from the testing of the real material sample**
  - material have to be homogenous
  - test samples in the appropriate shape (cylinder strength, cubic strength...)

Test samples

- shaping from the material
  - cutting, carving, drilling
- directly made in the required shape
  - cubes, cylinders..
- whole products
  - bricks, blocks

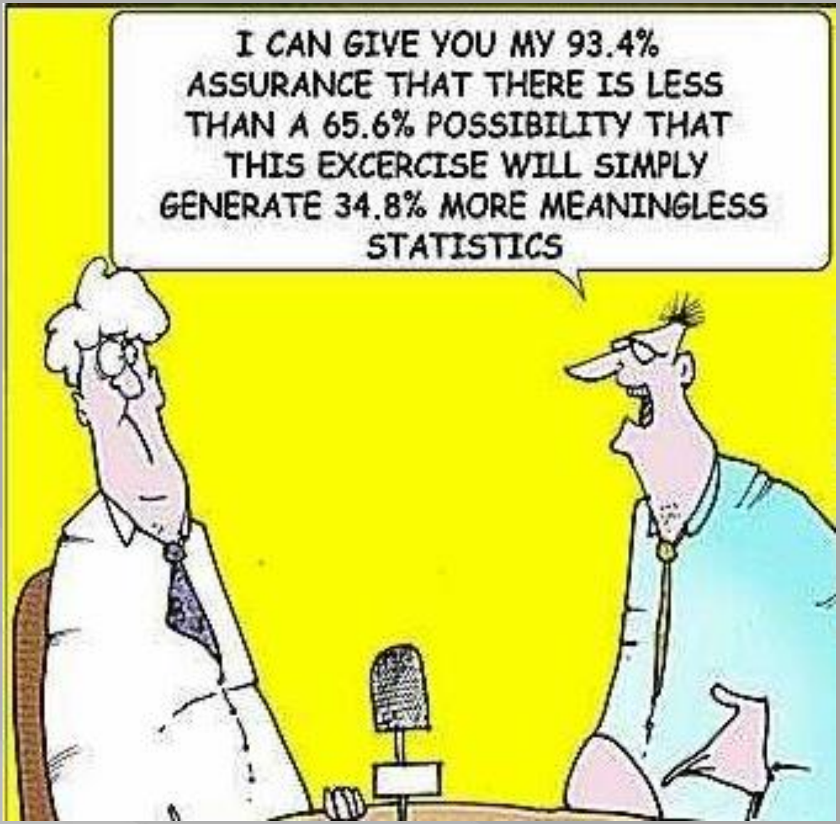
Department of Materials Engineering and Chemistry

Faculty of Civil Engineering

Building materials

Statistical strength

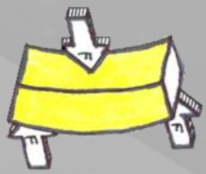
- from the single samples properties the property of the whole population can be estimated by the statistical methods



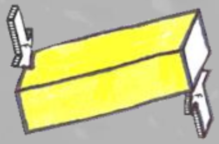
Strength testing according the loading

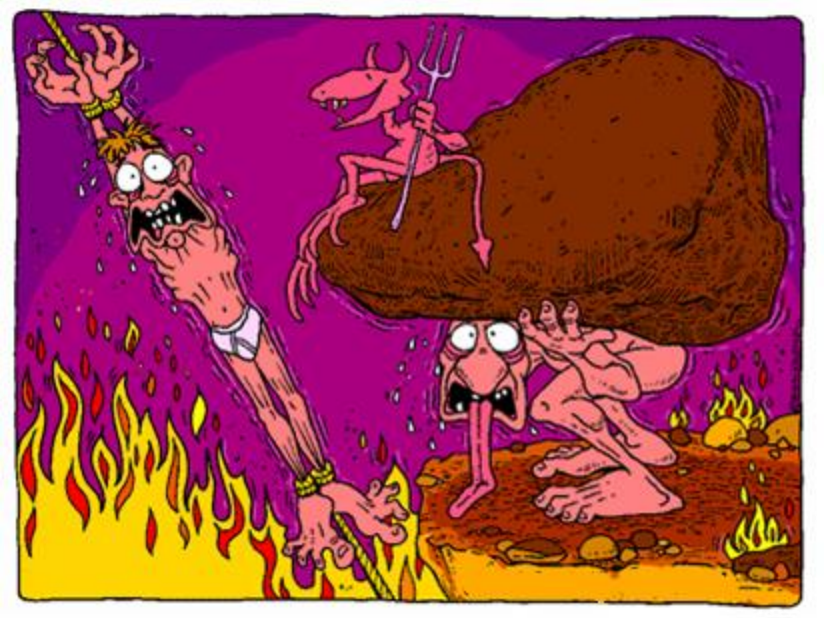

compression


tension


bending


torsion


shear

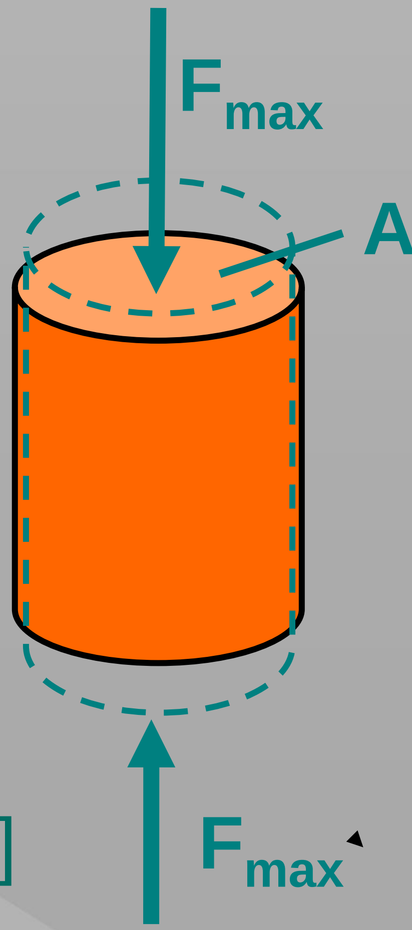


Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Compressive strength

• maximum resistance of a material to axial compressive loading

$$R_c = \frac{F_{\max}}{A}$$ [MPa]

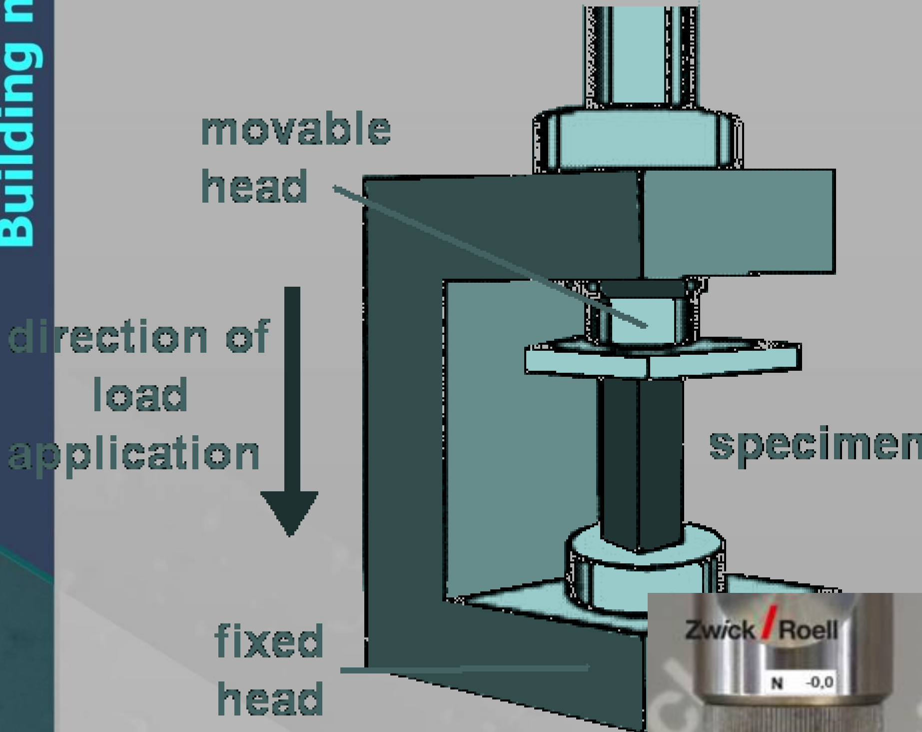


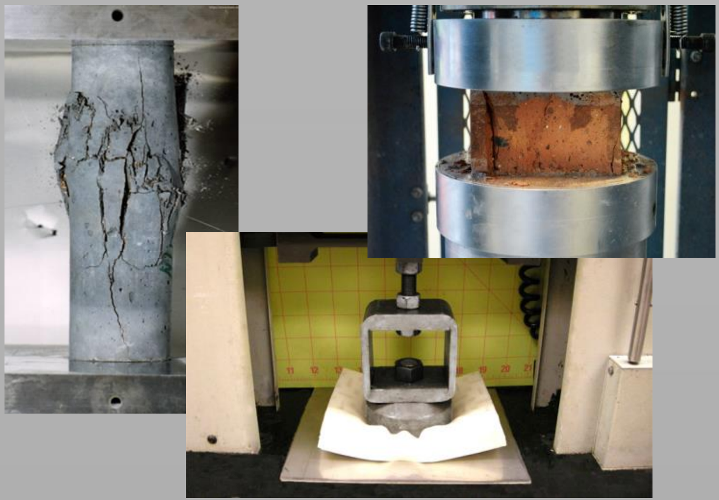
F_{max} .... maximum force [N]

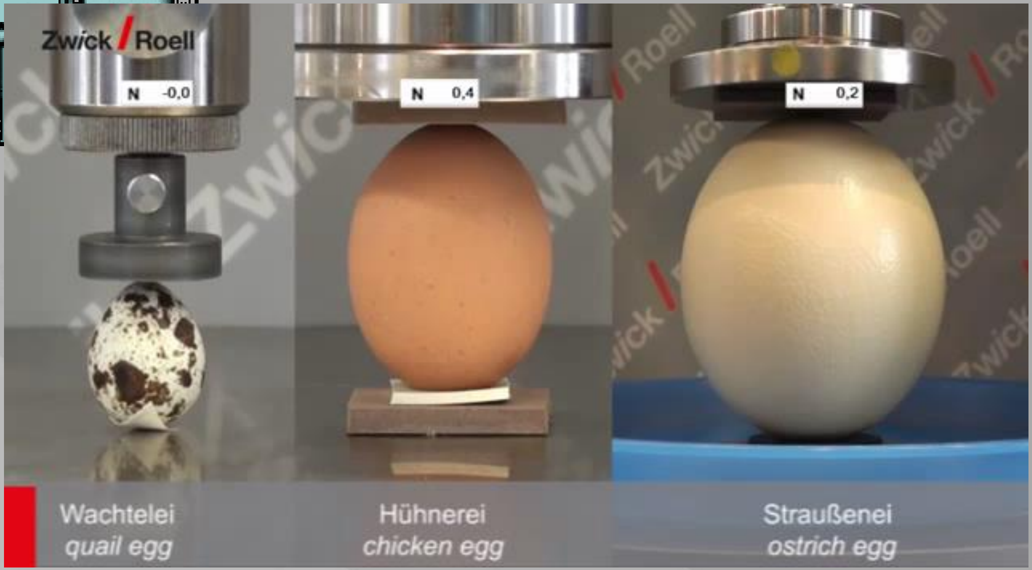
A ...... compressed area (cross-sectional) [mm]

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Compressive strength - testing







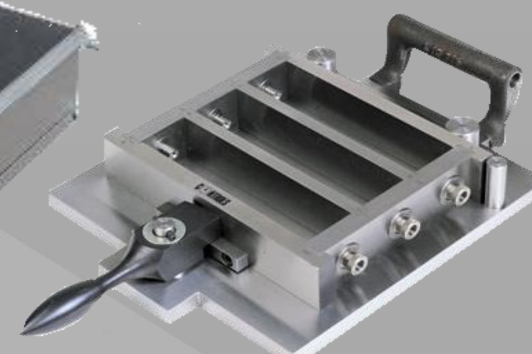
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Test specimen for compressive test

Regular shape:

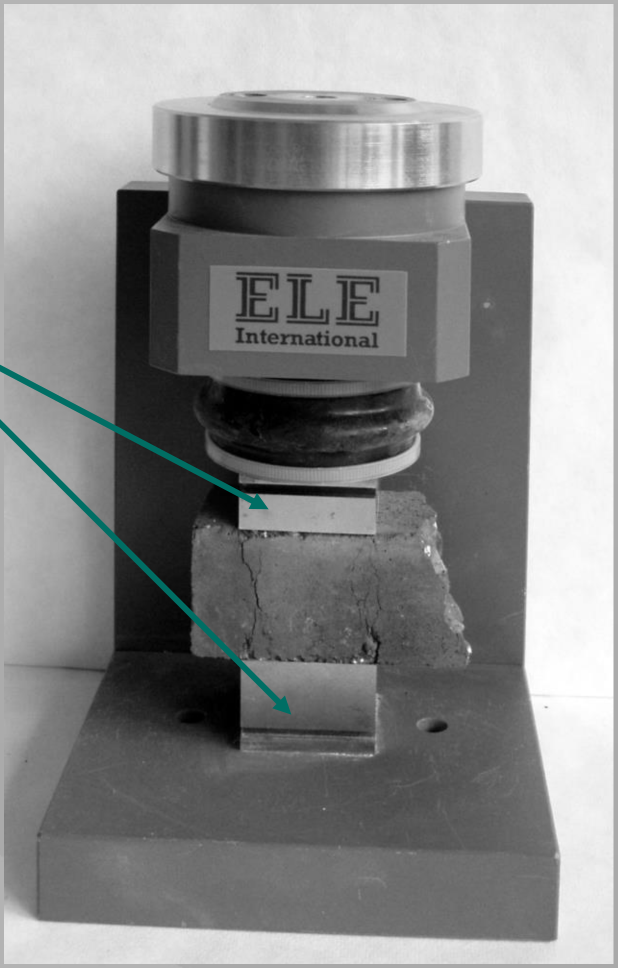
- **cubes** (concrete)
- **cylinders** (concrete, lightweight concretes)
- **beams** (lightweight concretes)
- **prism halves** (cement)
- **whole product** (block, brick)



Test specimen for compressive test

- irregular shape
  - **auxiliary plates**

- compressed area **A** given by the area of plates



Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Compressive strenght

Concrete C 25/30

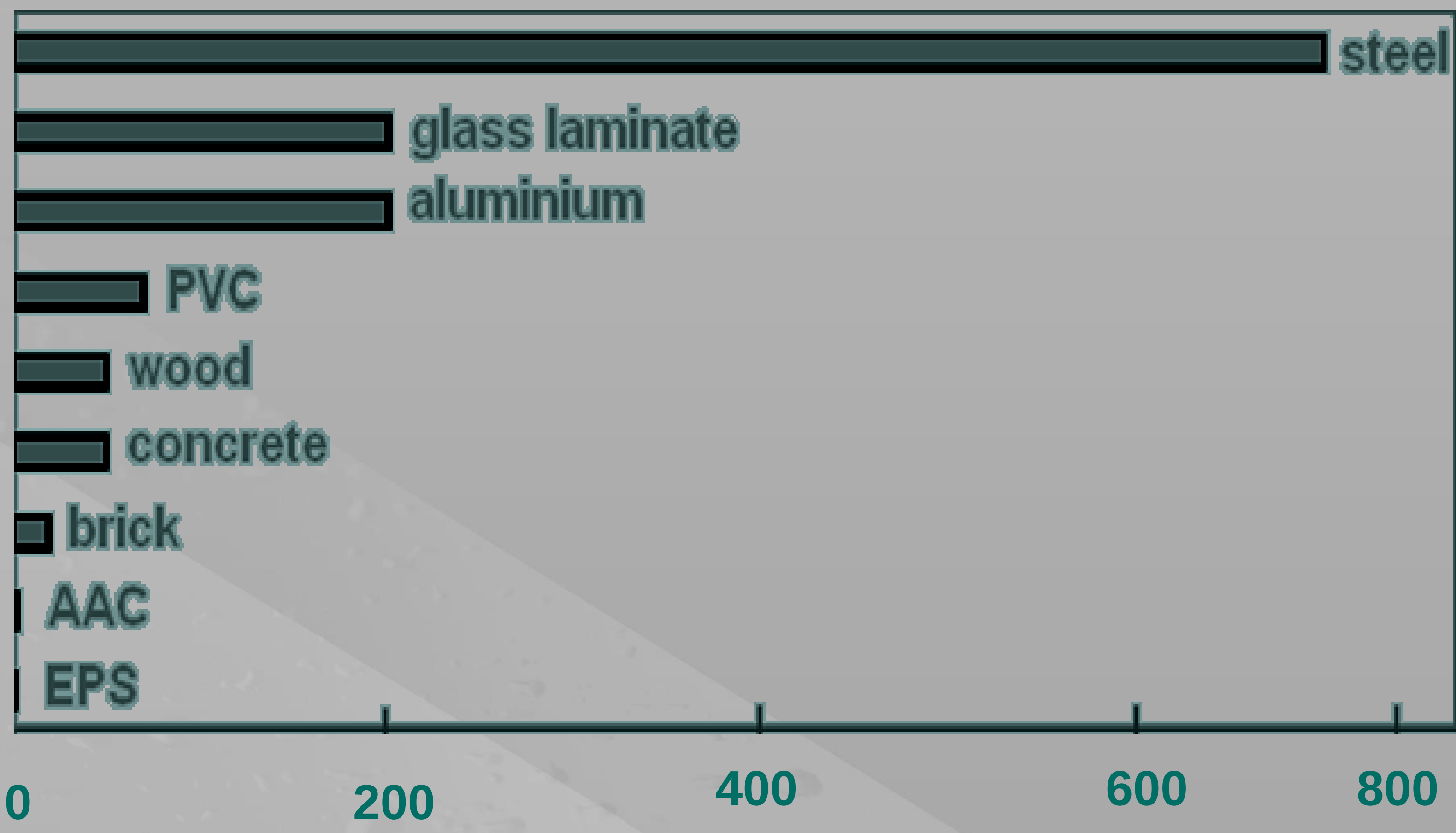
cylinder strength < cube strength

– the influence of friction between material surface and testing machine decreases with the height of the sample

Cylinder Strength		Cube Strength	
MPa	Psi	MPa	Psi
12	1740	15	2175
16	2320	20	2900
20	2900	25	3625
25	3625	30	4350
30	4350	37	5365
35	5075	45	6525
50	7250	60	8700

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Compressive strength of building materials



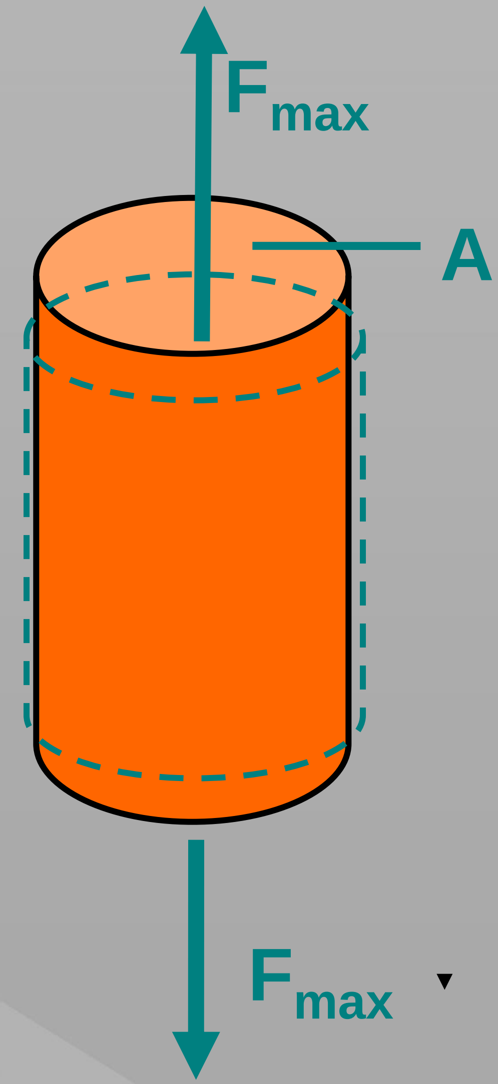
Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Tensile strength

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

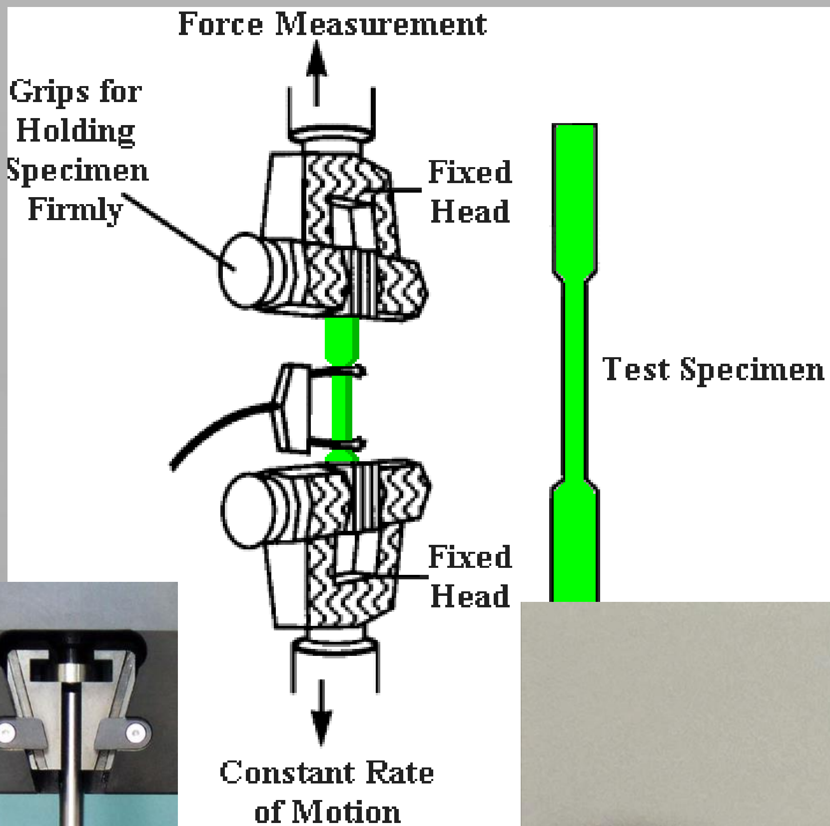
[MPa]



F_{max} .... maximum force [N]

A ...... area [mm]

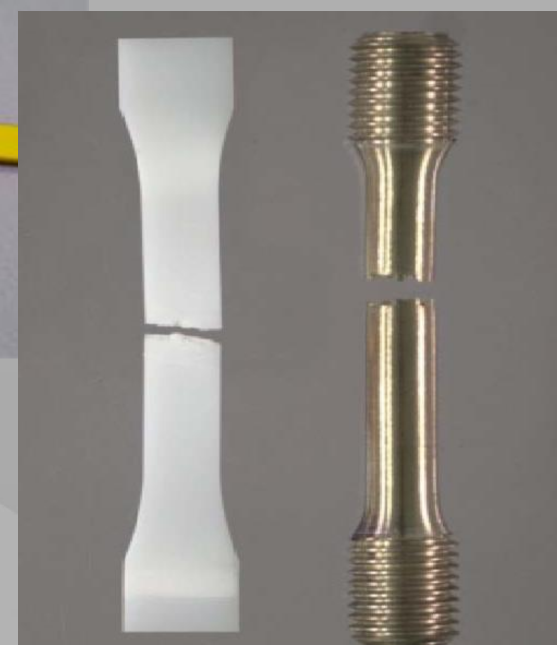
Tensile strenght - testing



Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Test specimen for tensile test

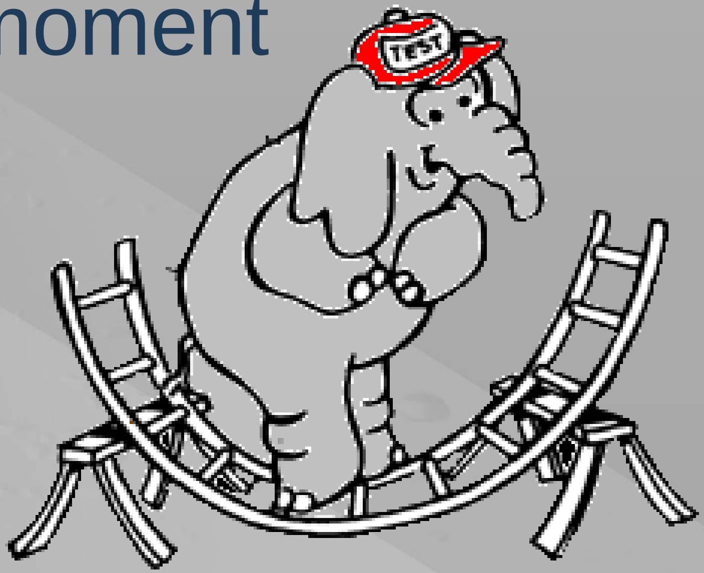
- **round or flat, slim**
- special shoulders for gripping in the machine



Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Flexural strength

- tensile strength of materials with distinctively higher compressive strength than tensile strength
- fracture in the place of the maximum bending moment

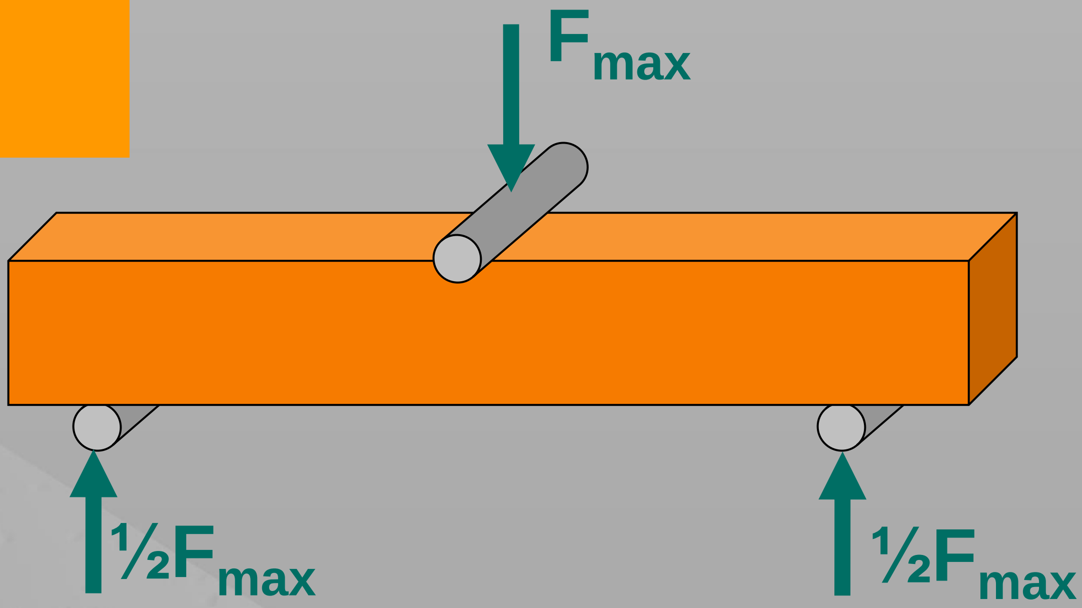


Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Flexural strength

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

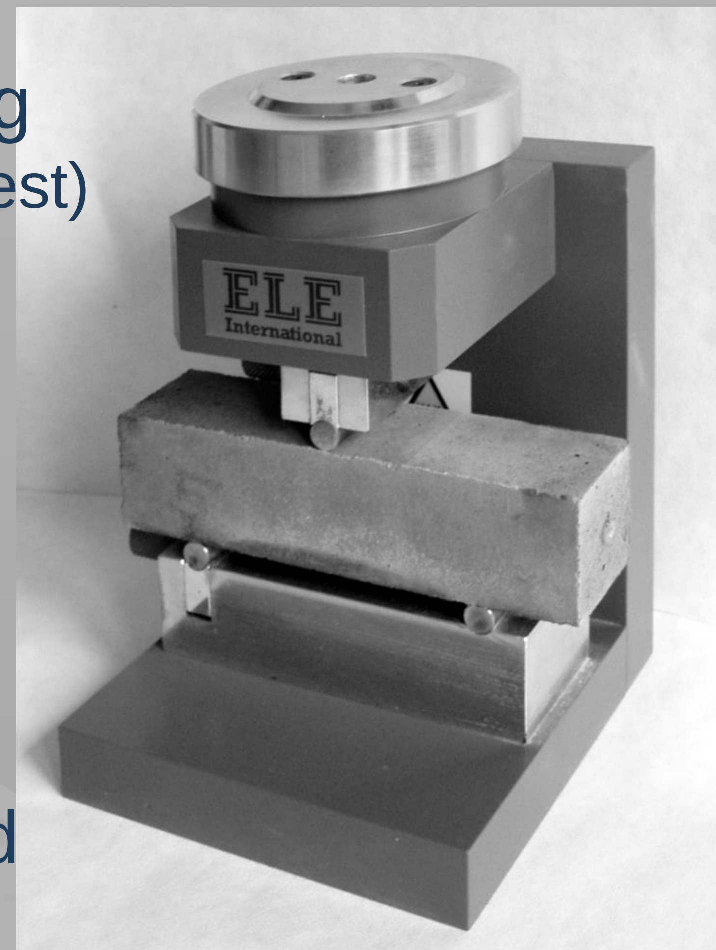


M_{max}..maximum bending moment [N.mm]

W ... section modulus [mm^3]

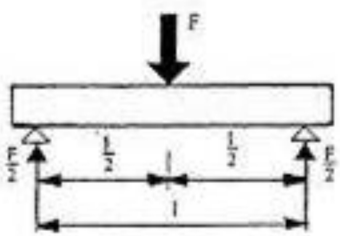
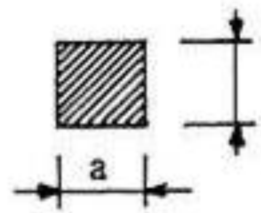
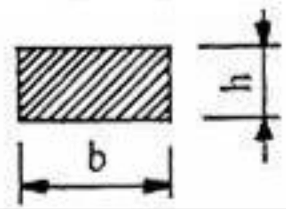
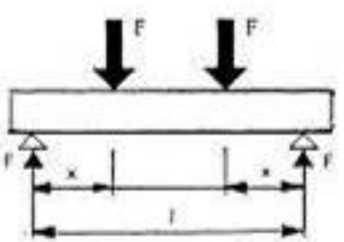
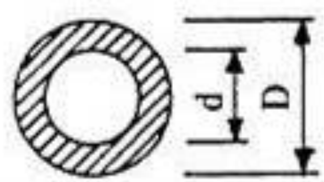
Flexural strength

- **Bending moment M**
  according type of loading
  (three point test, four point test)



- **Section modulus W**
  according the shape and
  size of cross section

Calculation of M and W

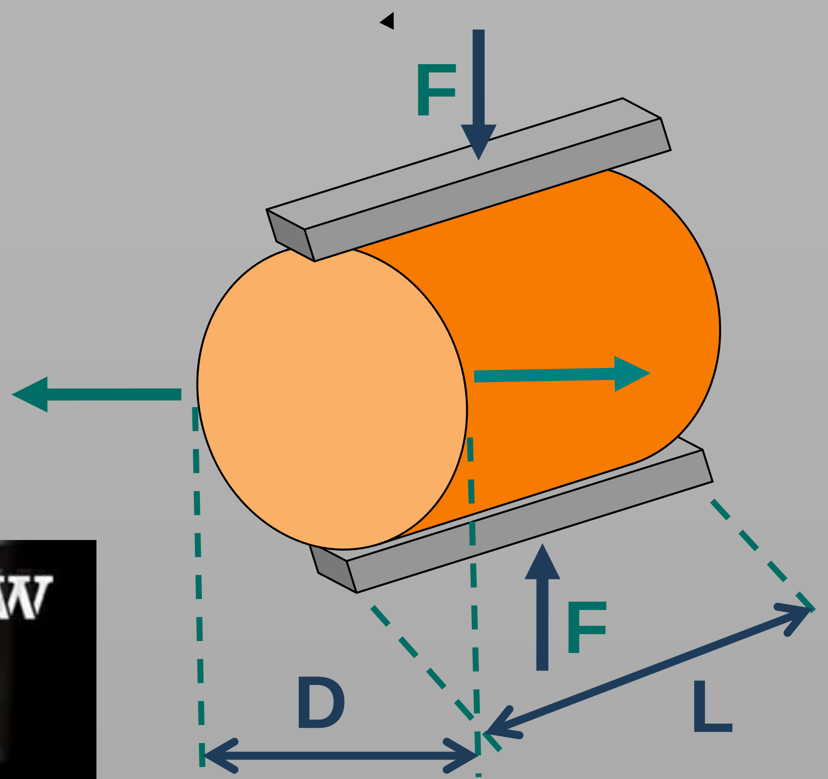
Loading diagram	Bending moment	Shape of cross-section	Section modulus
	$M = \frac{1}{4} F \times l$		$W = \frac{1}{6} a^3$
			$W = \frac{1}{6} bh^2$
	$M = F \times l$		$W = \frac{\pi}{32} d^3 = 0{,}1 d^3$
			$W = \frac{\pi (D^4 - d^4)}{32D}$

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Splitting tensile strength

- fragile materials

$$R_t = \frac{2F_{\max}}{\pi . D . l}$$



Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

Brazilian test

- stones

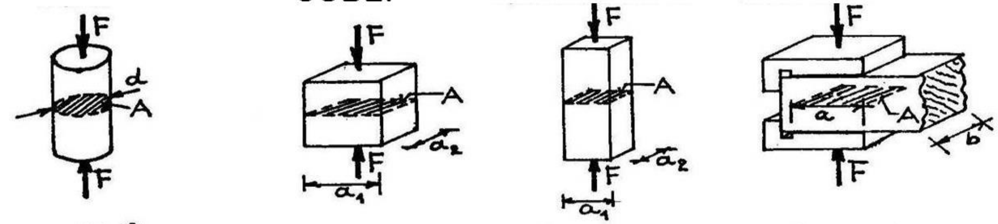
Rock	Compressive strength	Tensile strength
basalt	250 - 350	8
granite	80 - 280	3 - 8
limestone	40 - 200	1 - 6
sandstone	40 - 180	1.5 - 3
schist	60 - 200	2.5
marble	80 - 150	3 - 9
quartzite	300 - 500	3 - 5

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering

STRENGTH DETERMINATION

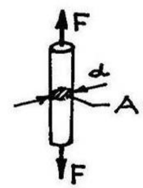
COMPRESSION:

CYLINDER: CUBE: PRISM: PRISM HALVE:



$R_c = \frac{F_{max}}{A}$ $A = \frac{\pi \cdot d^2}{4}$ $A = a_1 \cdot a_2$ $A = a_1 \cdot a_2$ $A = a \cdot b$

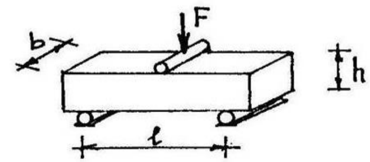
TENSION:



$A = \frac{\pi \cdot d^2}{4}$

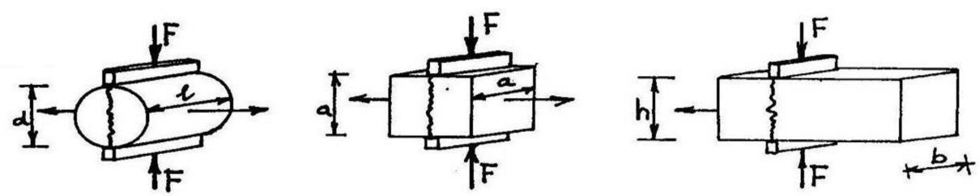
$R_t = \frac{F_{max}}{A}$

FLEXURE:



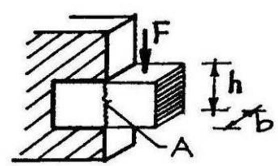
$R_f = \frac{3 \cdot F_{max} \cdot l}{2 \cdot b \cdot h^2}$ *)

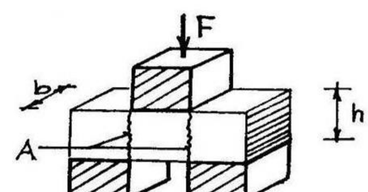
SPLITTING:



$R_t = \frac{2 F_{max}}{\pi \cdot d \cdot l}$ $R_t = \frac{2 \cdot F_{max}}{\pi \cdot a^2}$ $R_t = \frac{2 F_{max}}{\pi \cdot b \cdot h}$

SHEAR:





$A = b \cdot h$

$R_s = \frac{F_{max}}{A}$ $R_s = \frac{F_{max}}{2A}$

Department of Materials Engineering and Chemistry
Faculty of Civil Engineering