Building Materials

Lecture 2

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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**

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Scales

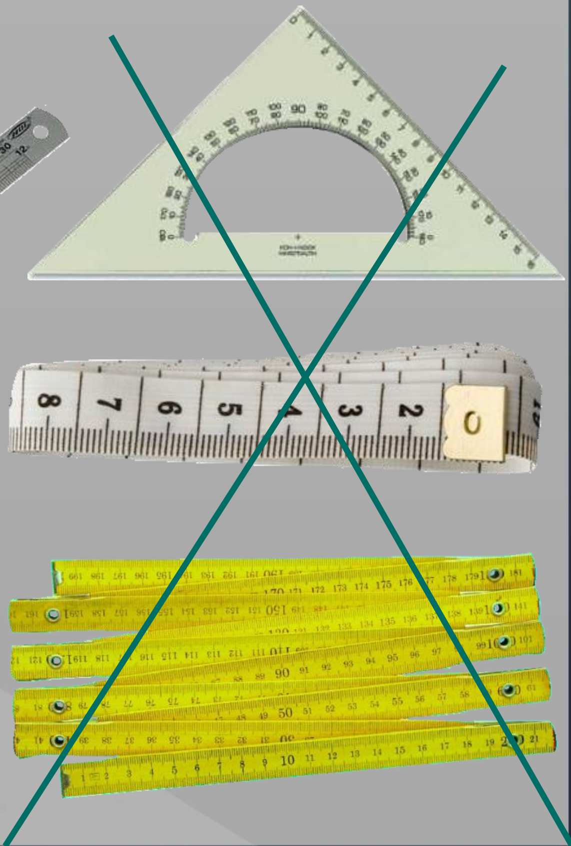
Mechanical , digital

- **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**



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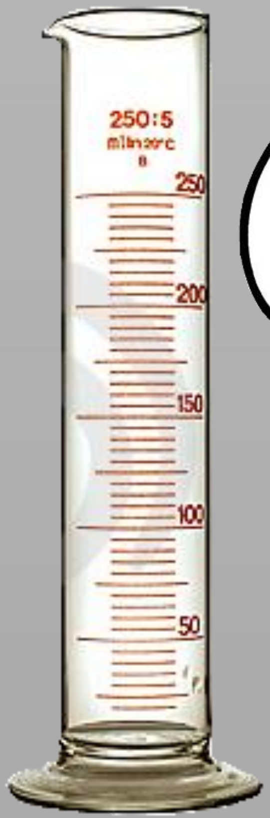
Volume

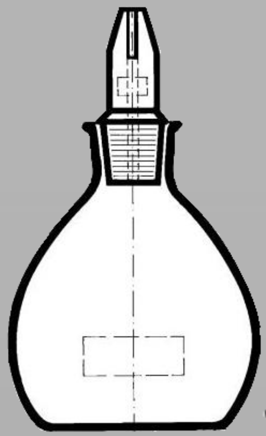
Solids:

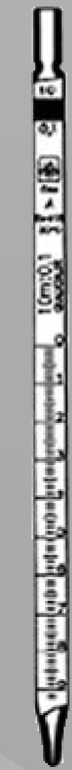
- **Calculation based on dimensions**
- **Immersion in liquid**
  - graduated cylinder
  - pycnometre
  - hydrostatic scales

Liquids:

  - volumetric flask
  - pipette
  - burette







Bulk density X Density
(matrix density)

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

[$kg.m^{-3}$]

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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

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Bulk density x Density

AAC

(aerated autoclaved concrete)

concrete

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

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

Bulk density determination

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

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

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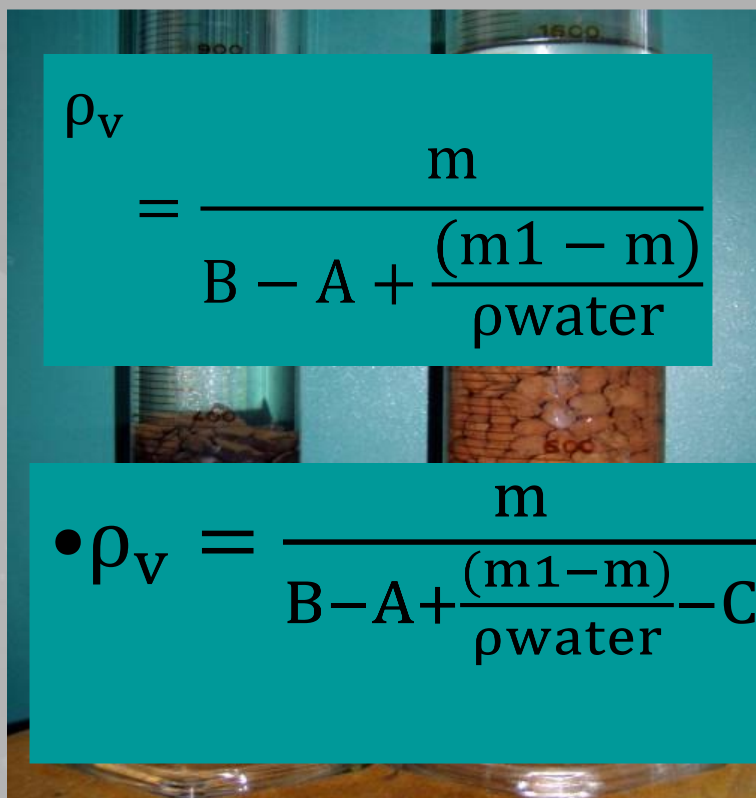
Bulk density determination:

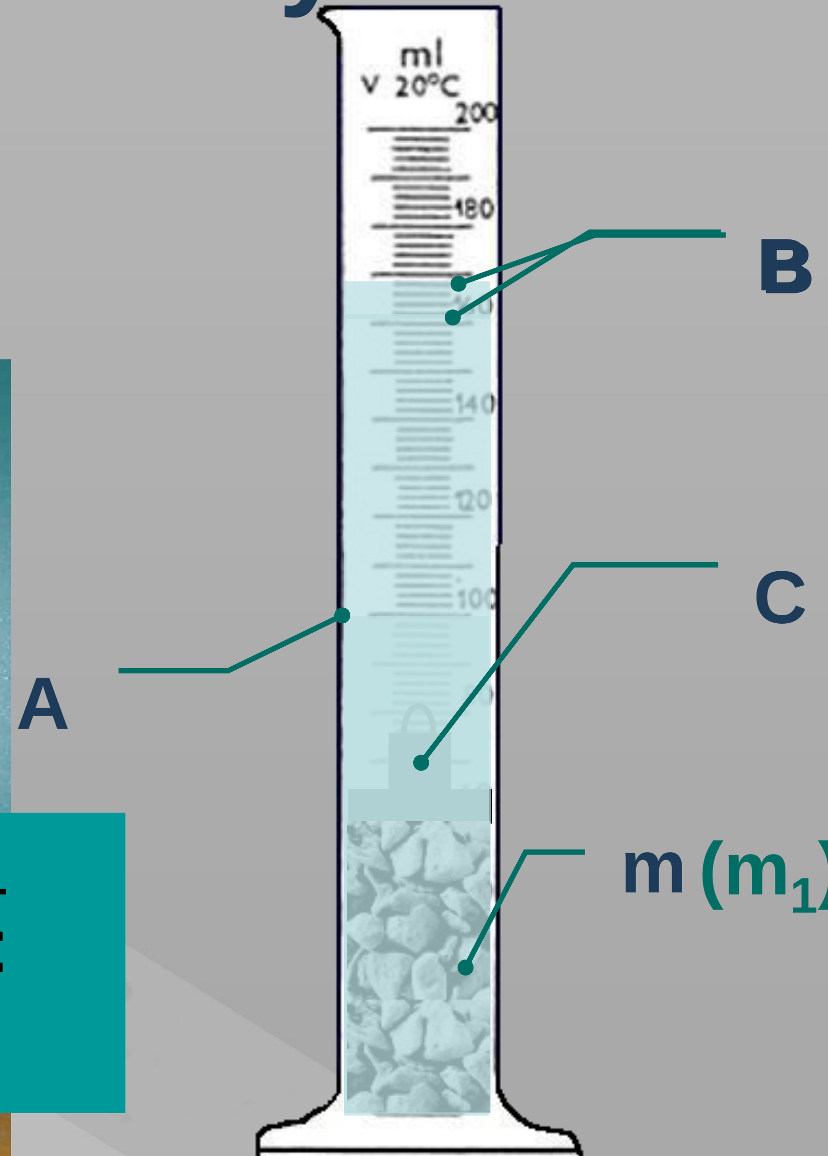
By graduated cylinder

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



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

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



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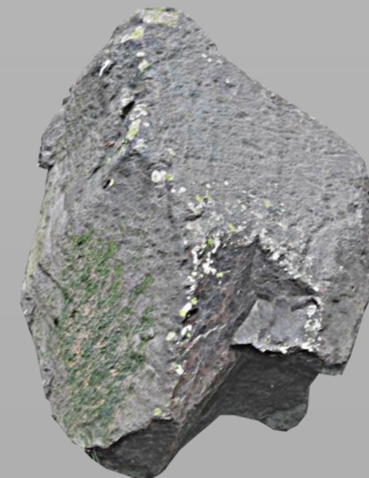
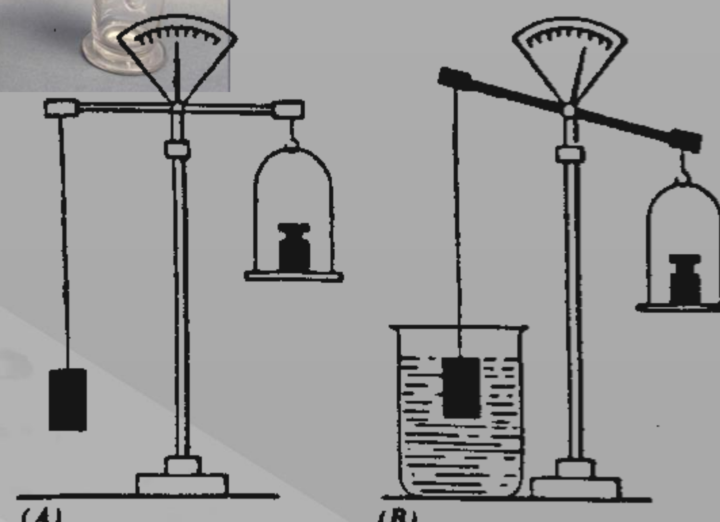
Bulk density determination:

By hydrostatical balance

- irregular shape → volume?





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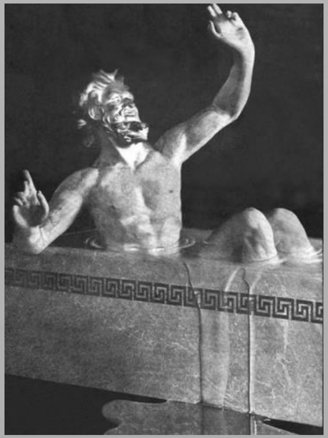
Bulk density determination:

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

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Bulk density determination:

By hydrostatical balance

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

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

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

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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

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Bulk density of building materials

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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 !

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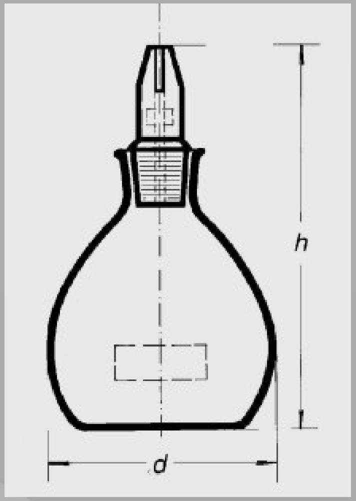
Pycnometer

- (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



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Determination of density by pycnometric method

m_1 m_2 m_3 m_4

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

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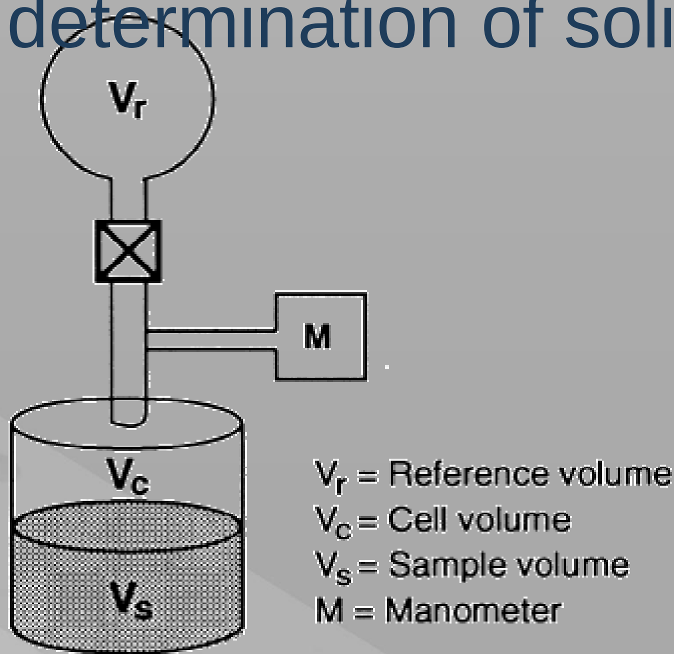
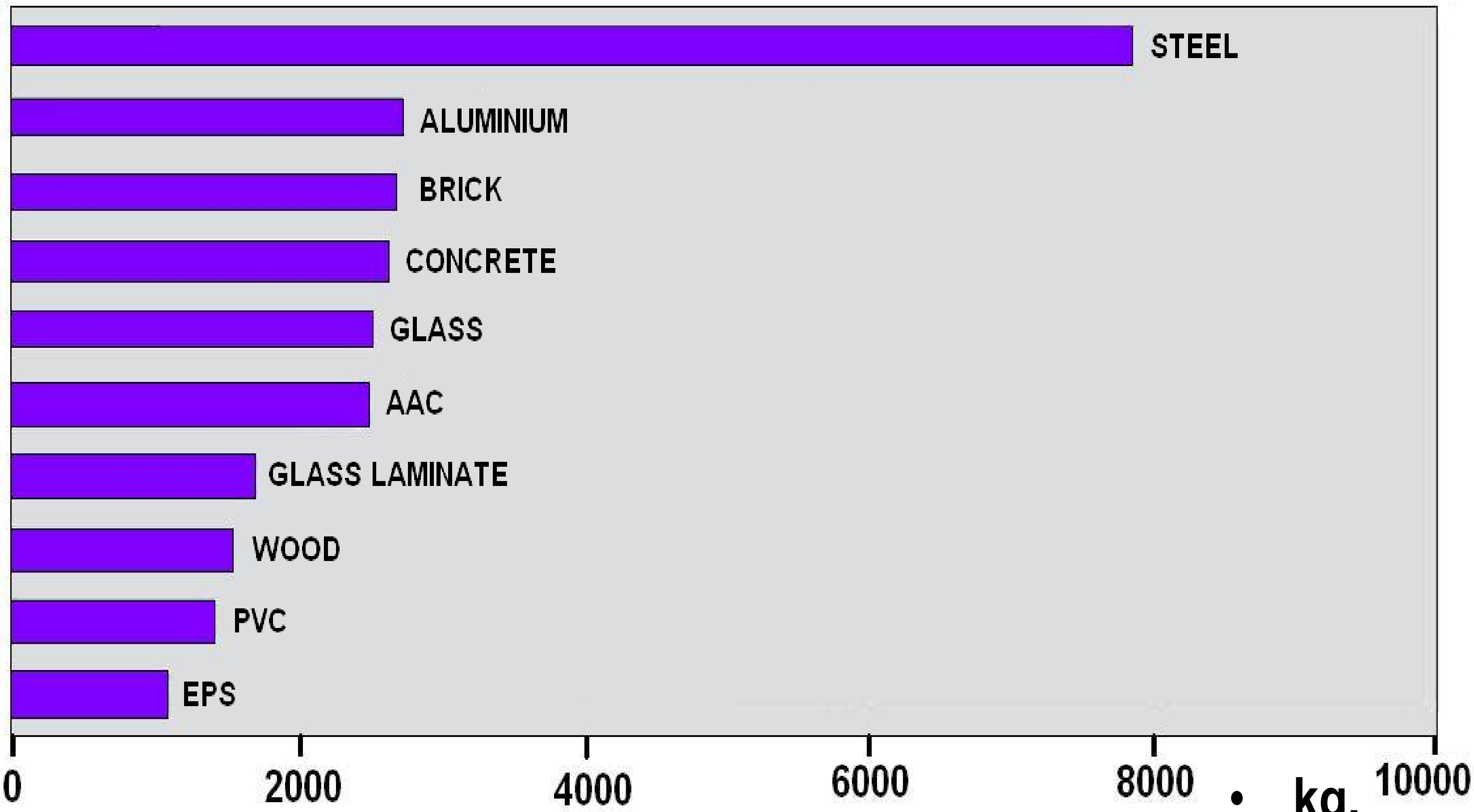
Helium pycnometer

- 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



Density of building materials



- $kg.m^{-3}$

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Porosity

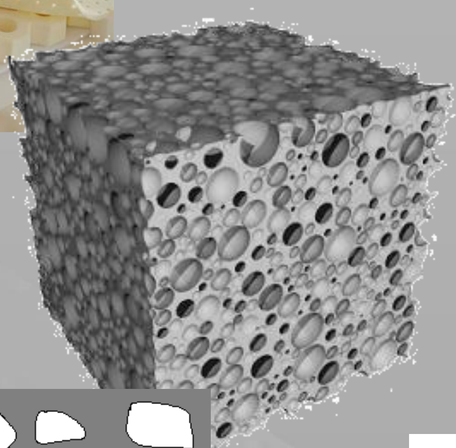
- **ratio of the volume of the pores to the total volume of the material**

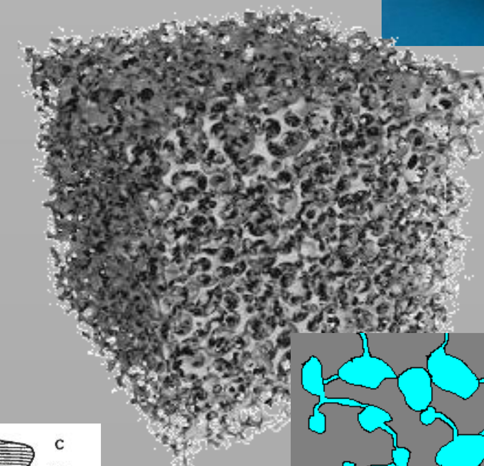
$$p = 1 - \frac{V_S}{V} = 1 - \frac{\rho_v}{\rho}.(100)$$

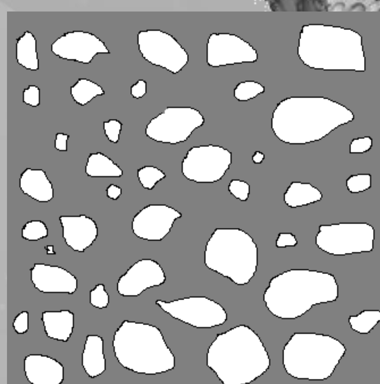
- usually expressed as a percentage

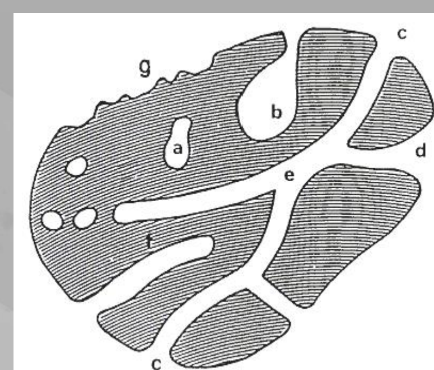
Types of pores

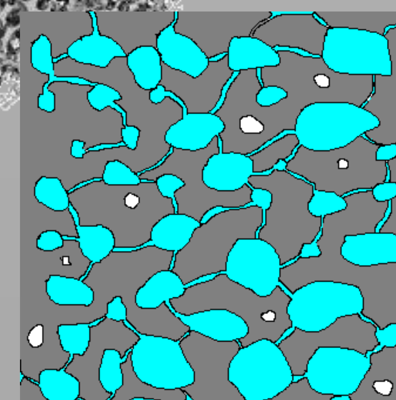
- closed
- open











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

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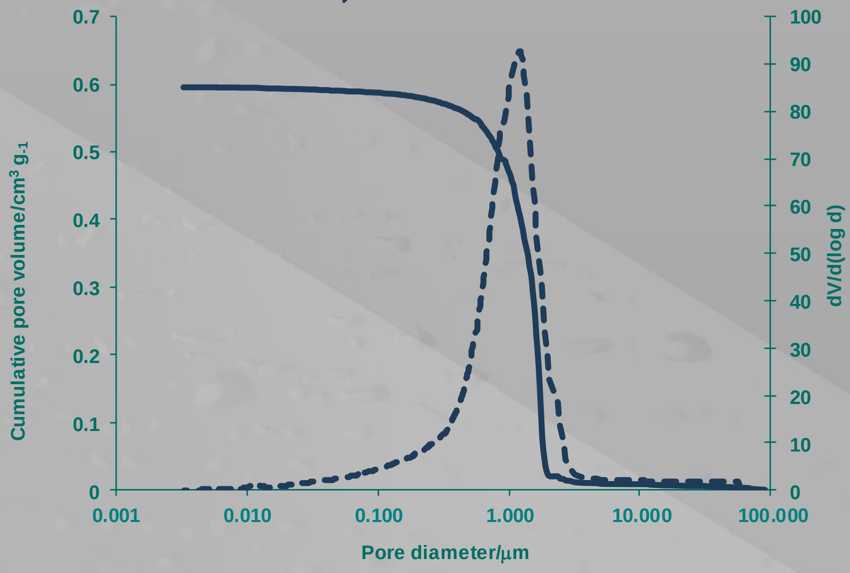
Properties related to porosity

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

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



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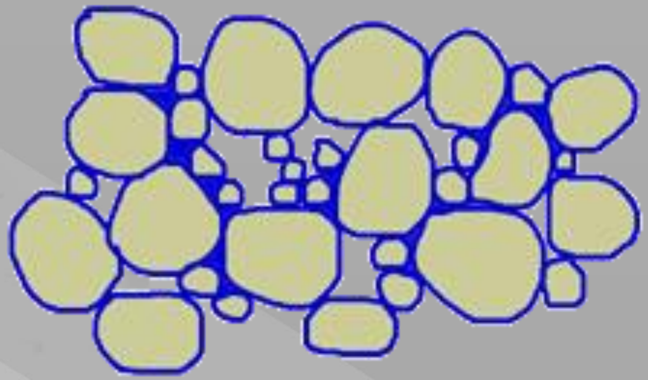
Properties of loose materials

Loose material = solid material divided into many small particles

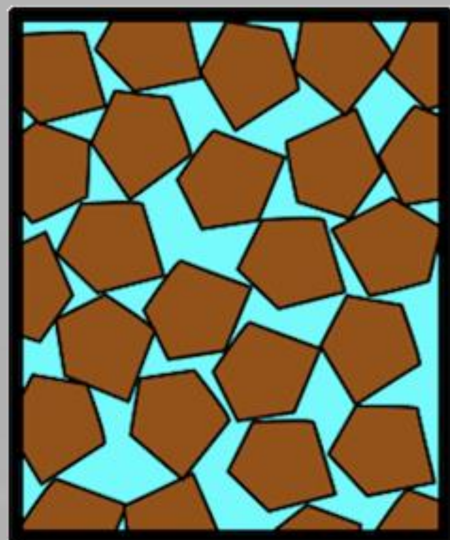
- an assembly of solid particles that is large enough for the statistical mean of any property to be independent of the number of particles

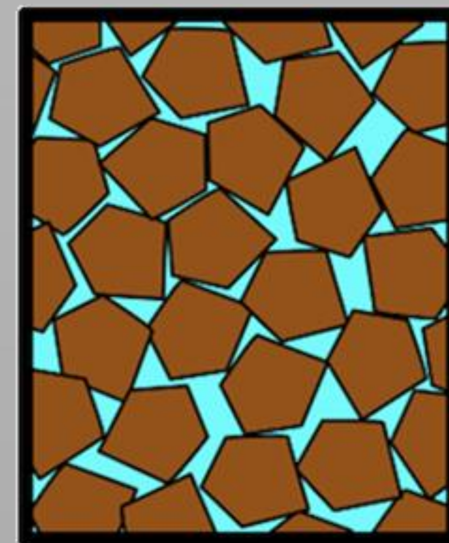
Void ratio

- 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

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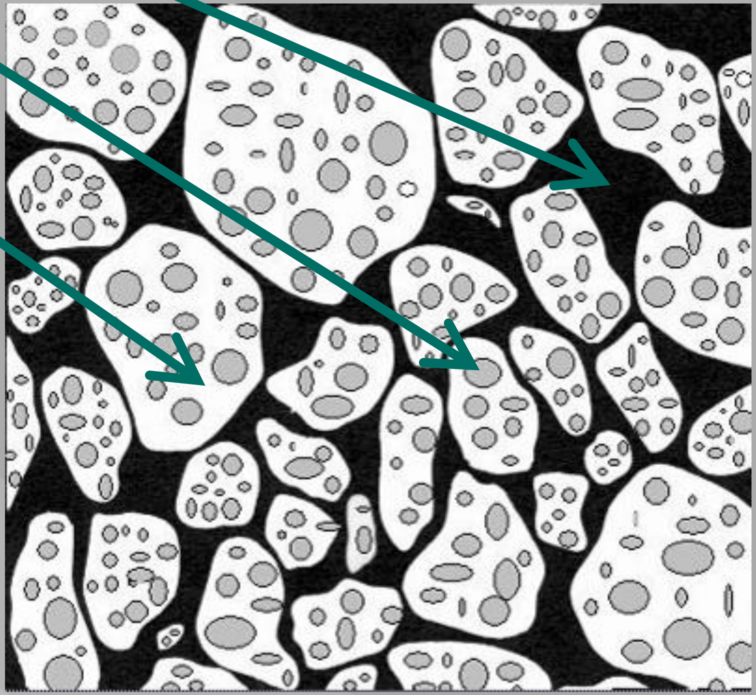
Loose (bulk) **density**

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

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



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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

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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

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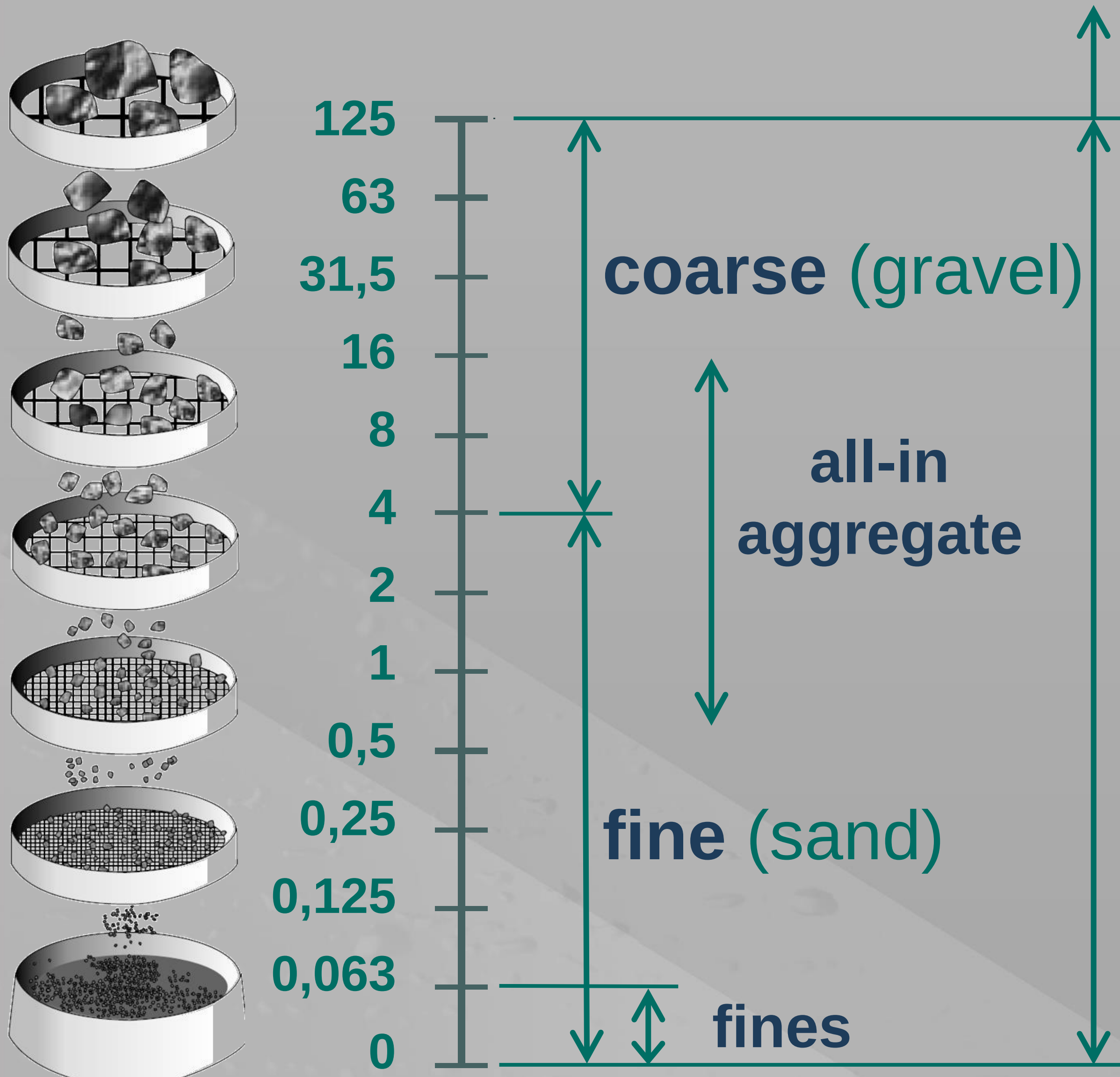
Standard sieves (EN 933-2)

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

Type of aggregates according size



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**)

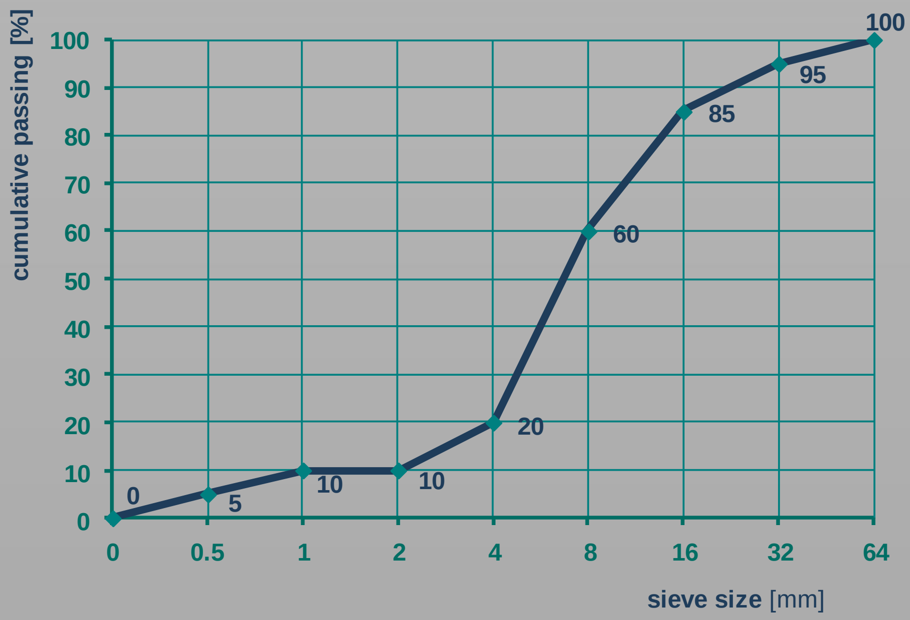
Sieve analysis - definitions

- **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)

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)

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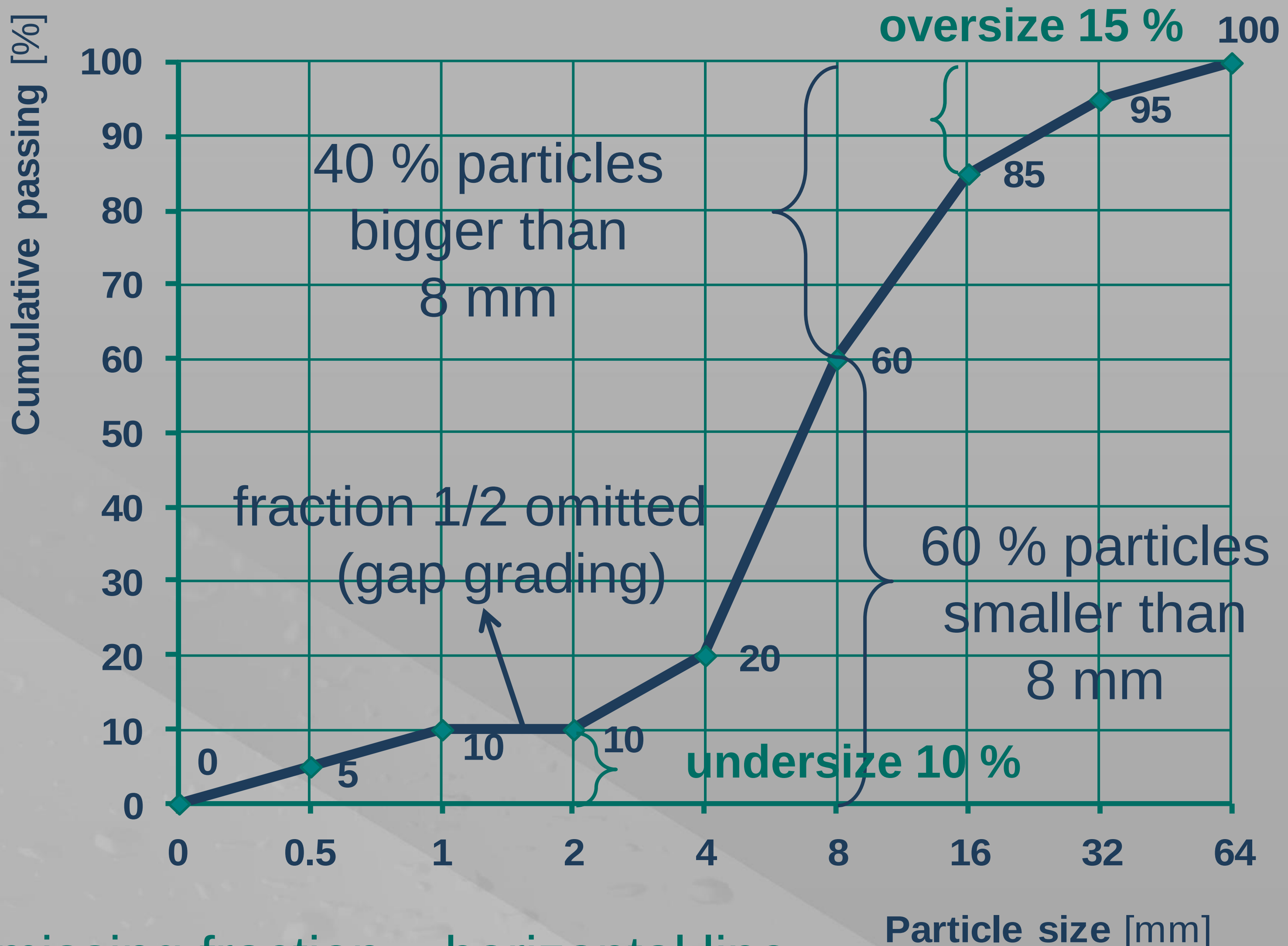
Example:

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

Particle size distribution curve



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

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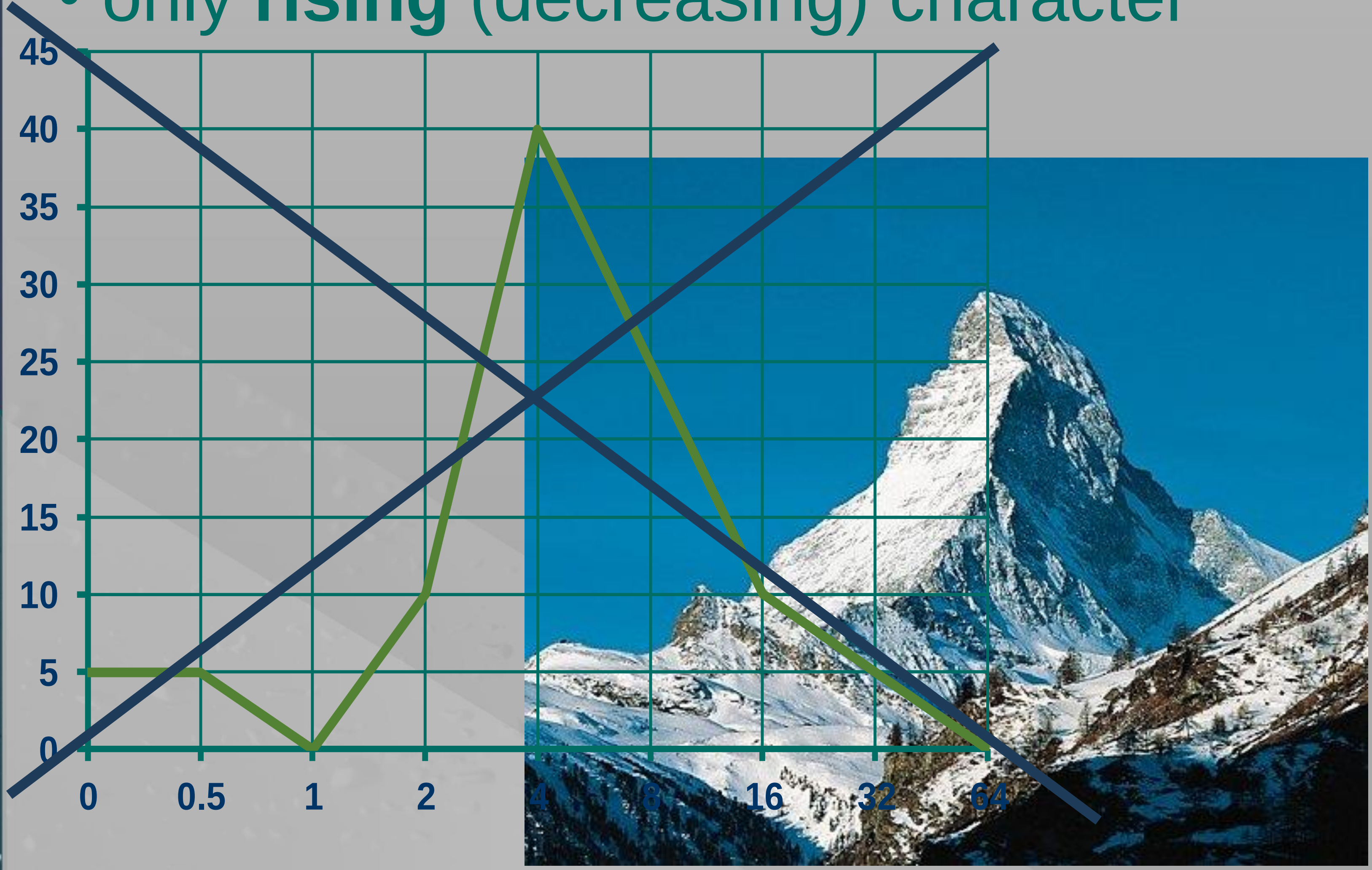
Particle size distribution curve

- only **rising** (decreasing) character



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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.

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

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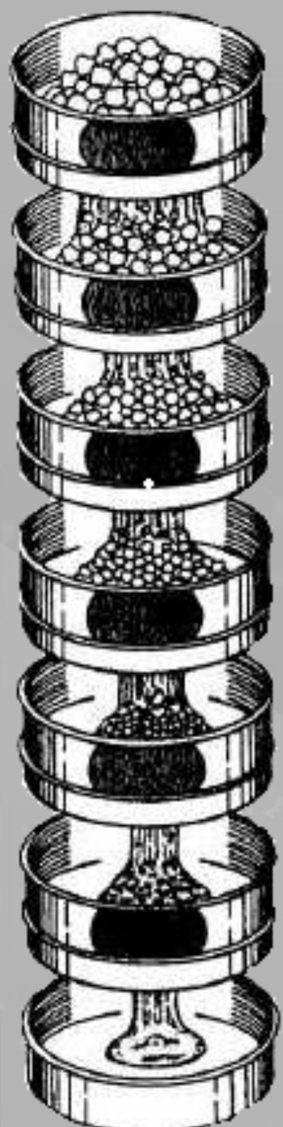
$$FM = \frac{\sum \text{cumulative retained on specified sieves } [\%]}{100\ \%}$$



Z_{16}

Z_8

Z_4

Z_2

Z_1

$Z_{0,5}$

Z_0

$$Z_{16}$$
$$+$$
$$Z_{16} + Z_8$$
$$+$$
$$Z_{16} + Z_8 + Z_4$$
$$+$$
$$Z_{16} + Z_8 + Z_4 + Z_2$$
$$+$$
$$Z_{16} + Z_8 + Z_4 + Z_2 + Z_1$$
$$+$$
$$Z_{16} + Z_8 + Z_4 + Z_2 + Z_1 + Z_{0,5}$$
$$+$$
$$Z_{16} + Z_8 + Z_4 + Z_2 + Z_1 + Z_{0,5} + Z_0$$

Fineness modulus

EN 12620

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

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

$$1 < \mathrm{FM} < 6$$

- **the bigger FM is, the coarser is aggregate**

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Fines

= particle size fraction which passes the 0.063 mm sieve

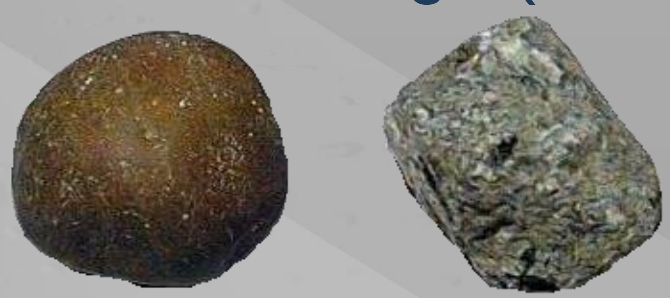
- several **methods for determining** (washing, sand equivalent test, methylene blue test, air jet sieving)
- maximum value:
  - fine aggregate $<$ **3 %**
  - coarse aggregate $<$ **1.5 %**
- higher content of fines:
  - higher consumption of cement
  - lower strength

Shape and texture of particles

Particles:

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

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



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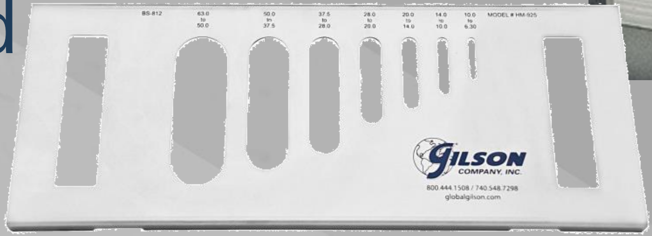
Flakiness index
(EN 933-3)

- 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



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

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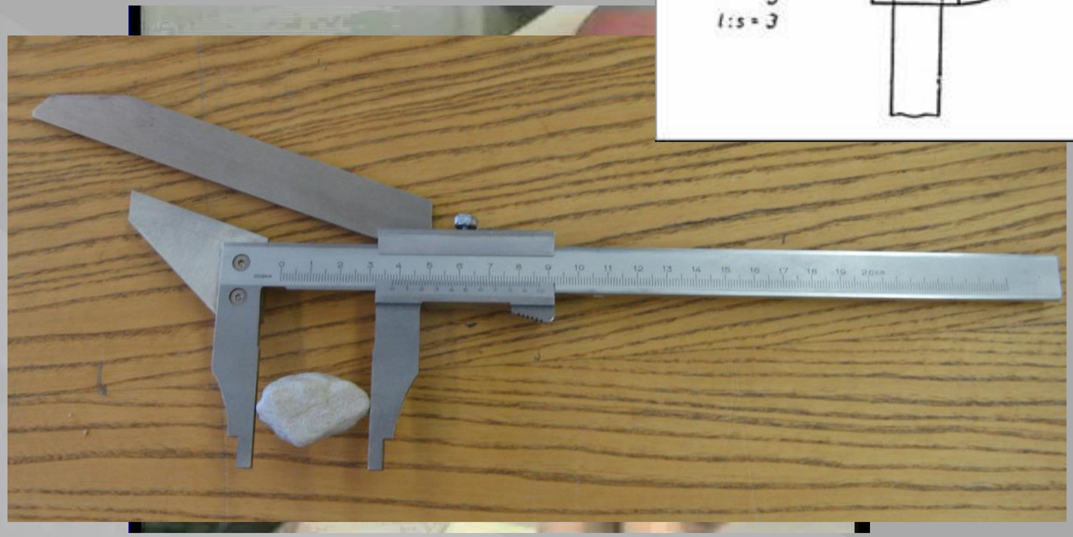
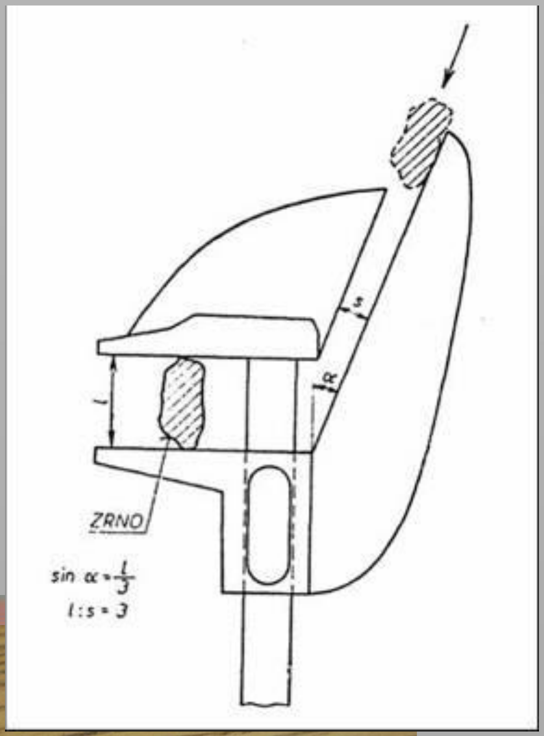
Shape ratio L/E





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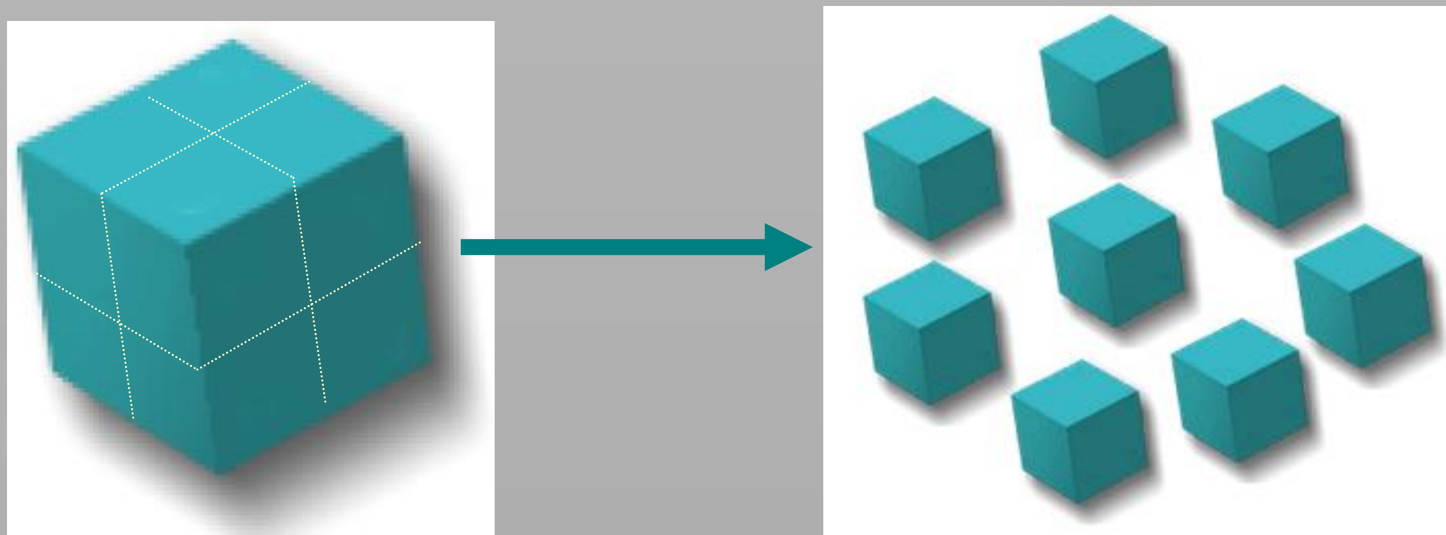
Specific surface

- **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

Specific surface



cube 2 x 2 x 2 cm

each face is 4 cm^2

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

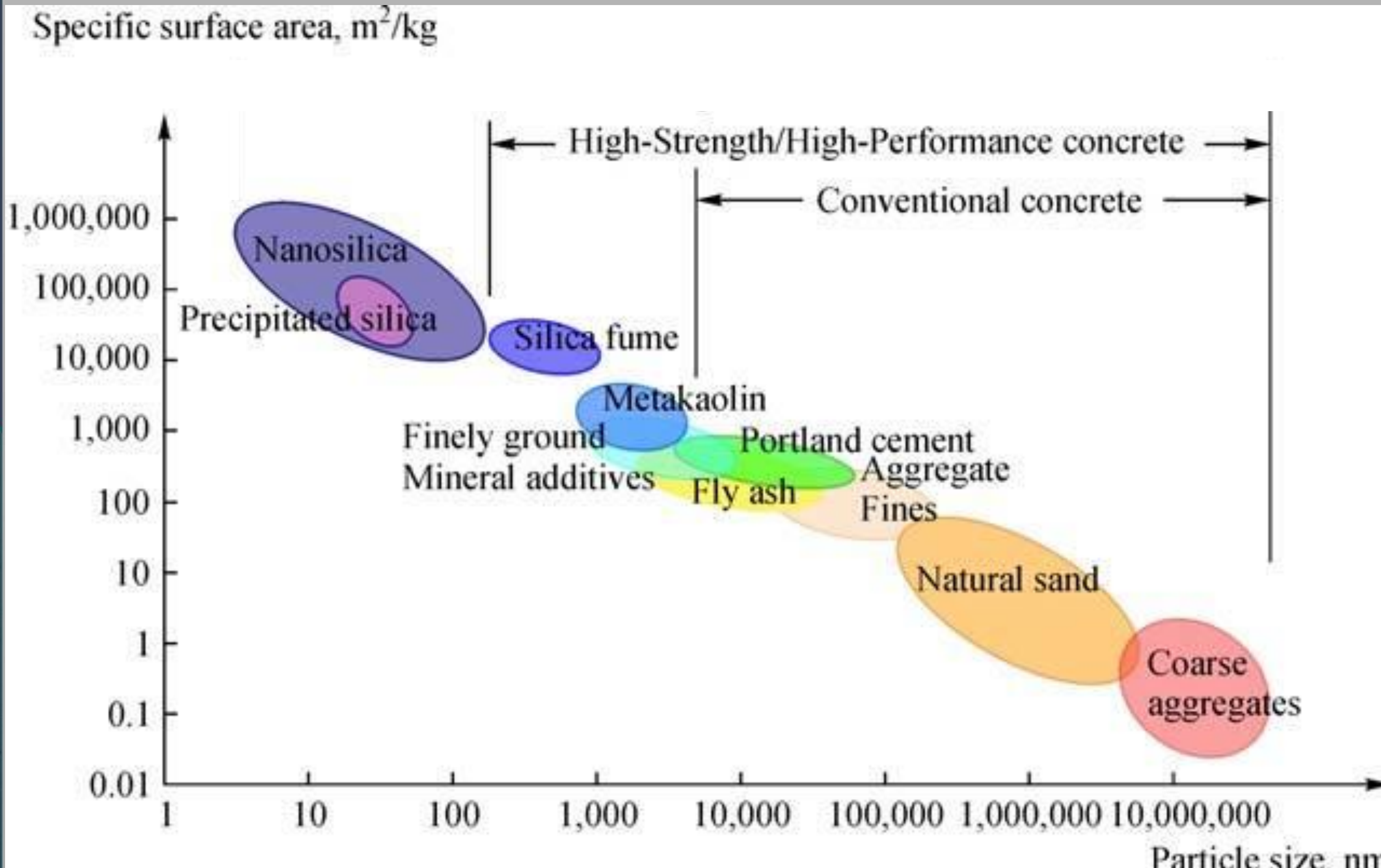
8 cubes 1 x 1 x 1 cm

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



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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**

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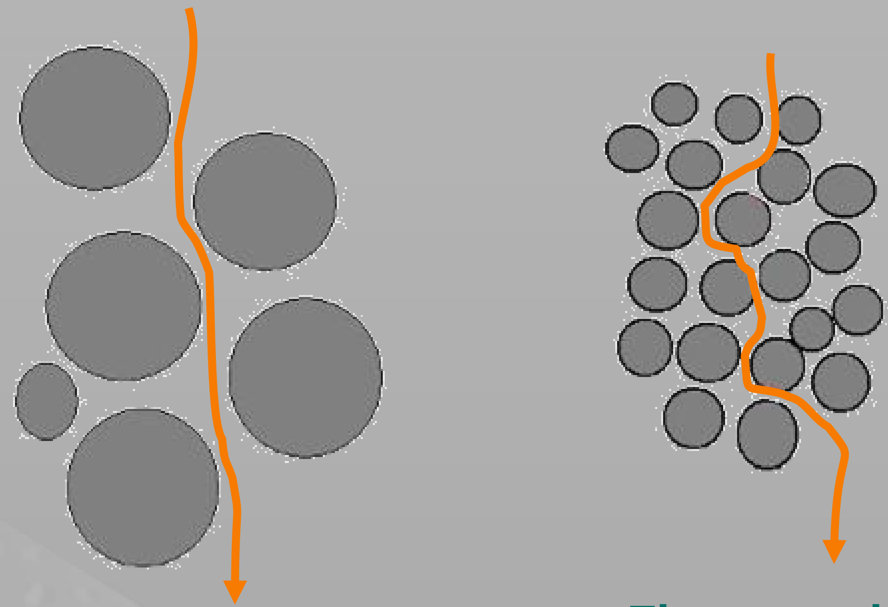
Air permeability method



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

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Blain apparatus

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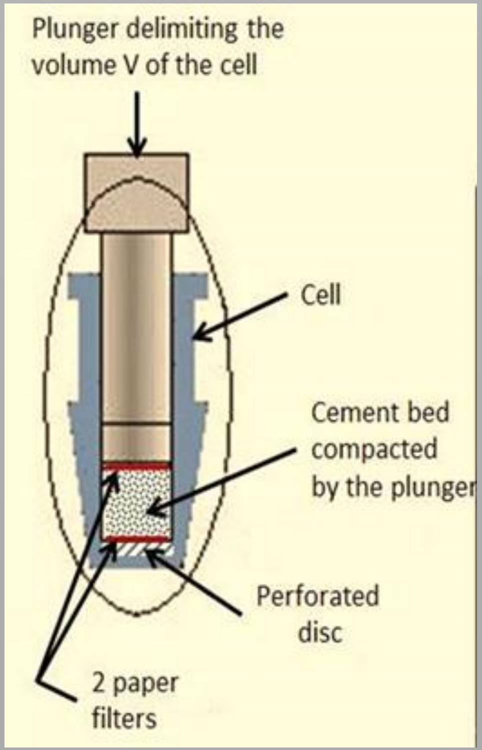
Blain apparatus

Ermittlung der spezifischen Oberfläche von Zement

Determining the specific surface area of cement

Specific surface calculation

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



- **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]

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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]

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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)

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Mechanical properties

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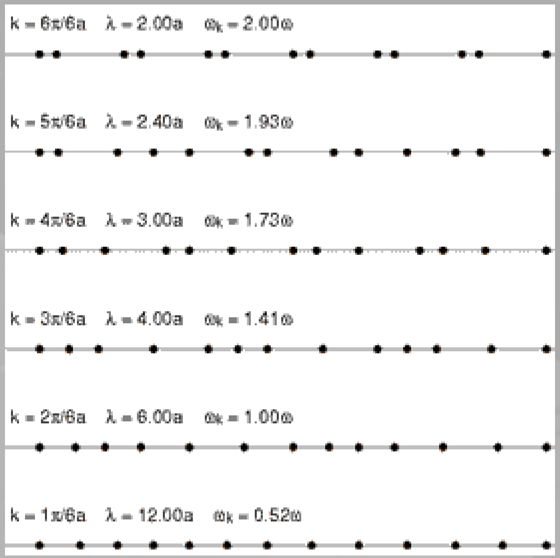
Solid materials

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



Atomic vibration in crystalline solid

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Mechanical properties

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

Mechanical properties

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

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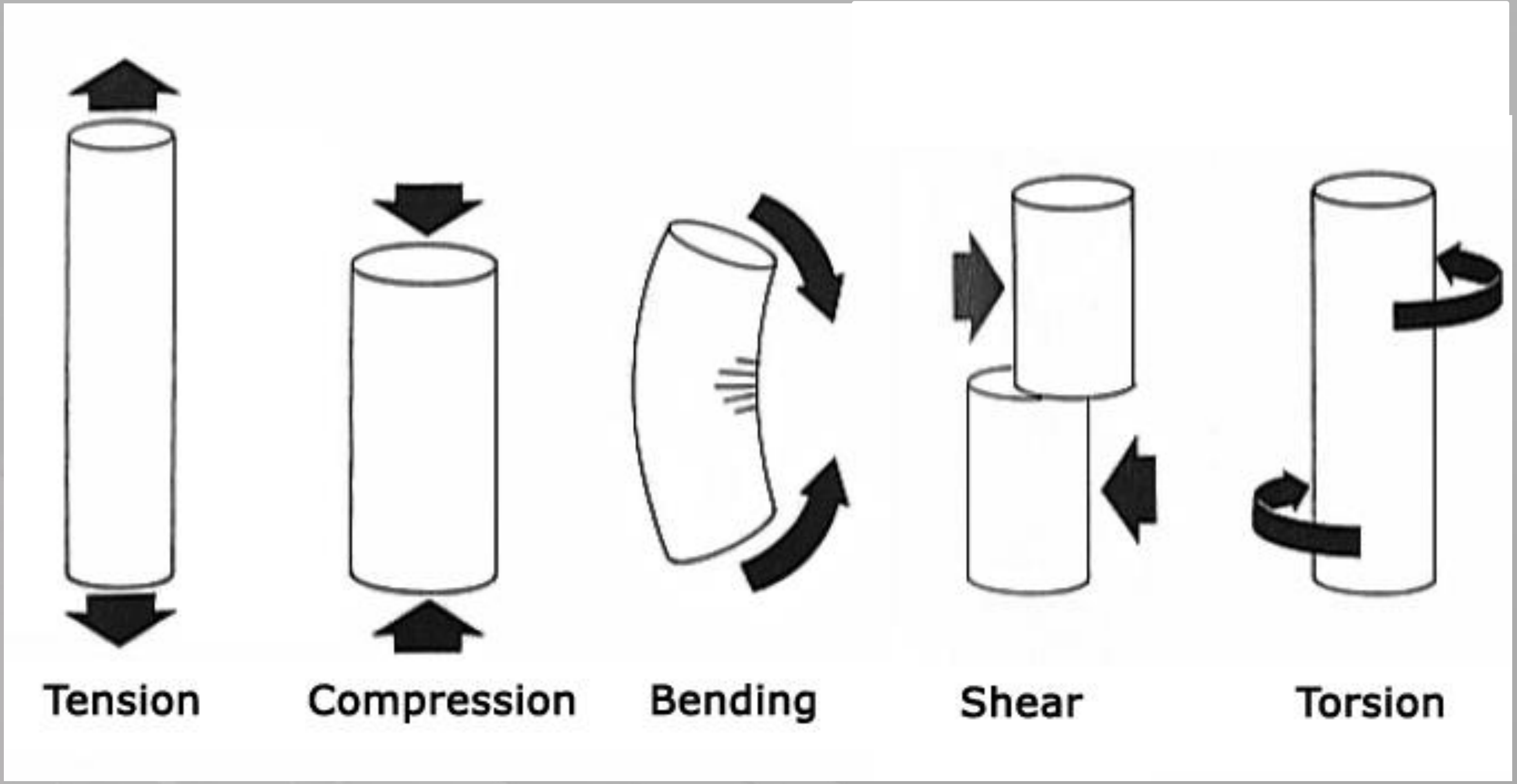
Type of loading



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**

Compressive stress

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

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

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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

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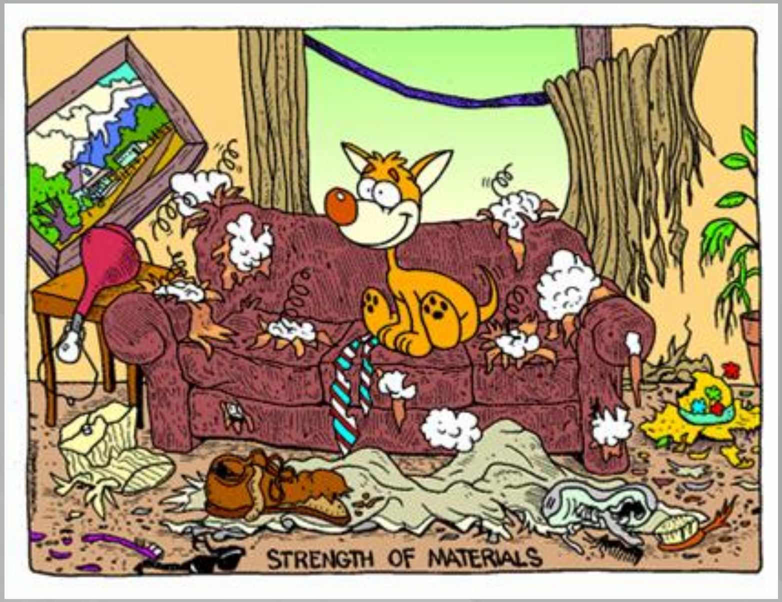
Strength properties

Strength

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



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Strength

According the way of obtaining:

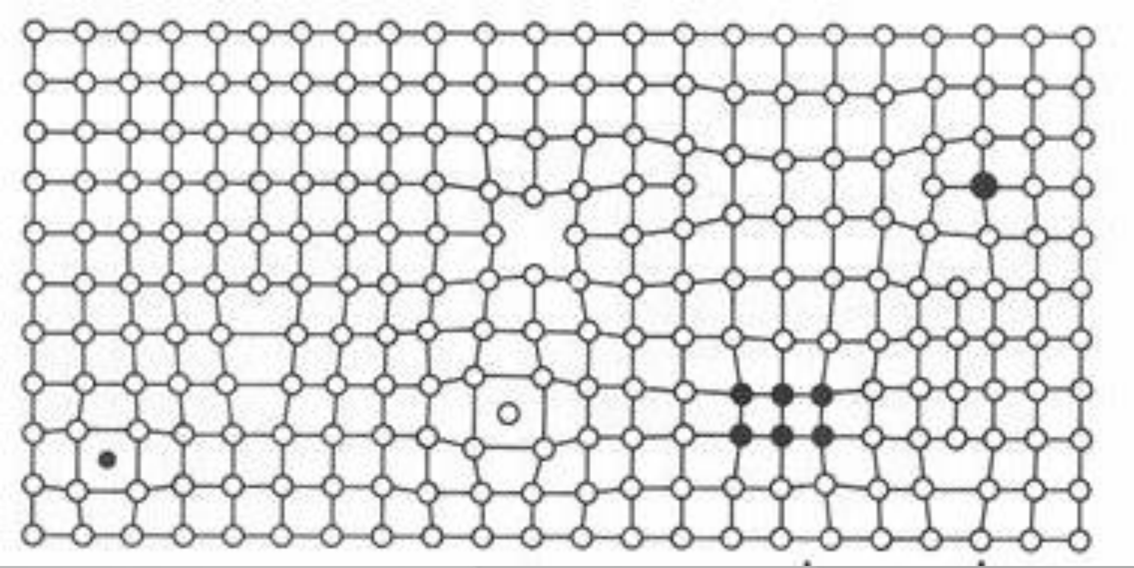
- **theoretical** (structural)
- **technical**
- **statistical**

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)



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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

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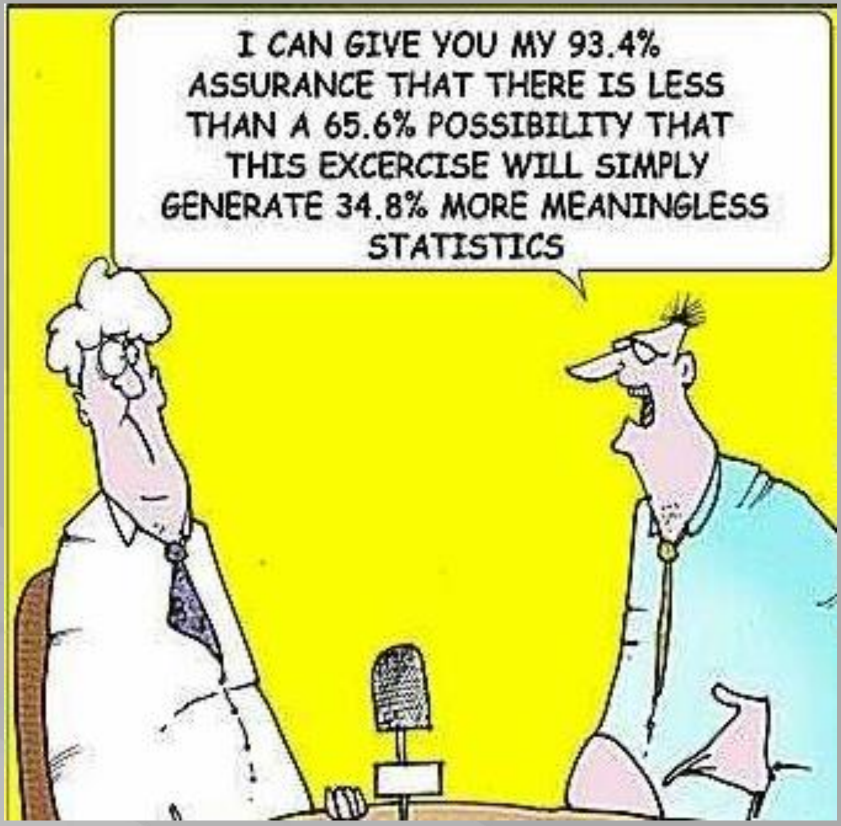
Statistical strength

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



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Statistics

„ The only statistics you can trust are those you falsified yourself.“

attributed to *Winston Churchill*

Statistics - terminology

- **Random experiment** - any experiment of which result cannot be precisely predicted
- **Population** – representative sample of larger group of individuals with one or more characteristics in common
- **Random sample** - a small random portion of the entire population selected in such a way that every member of the sample has equal probability of being chosen

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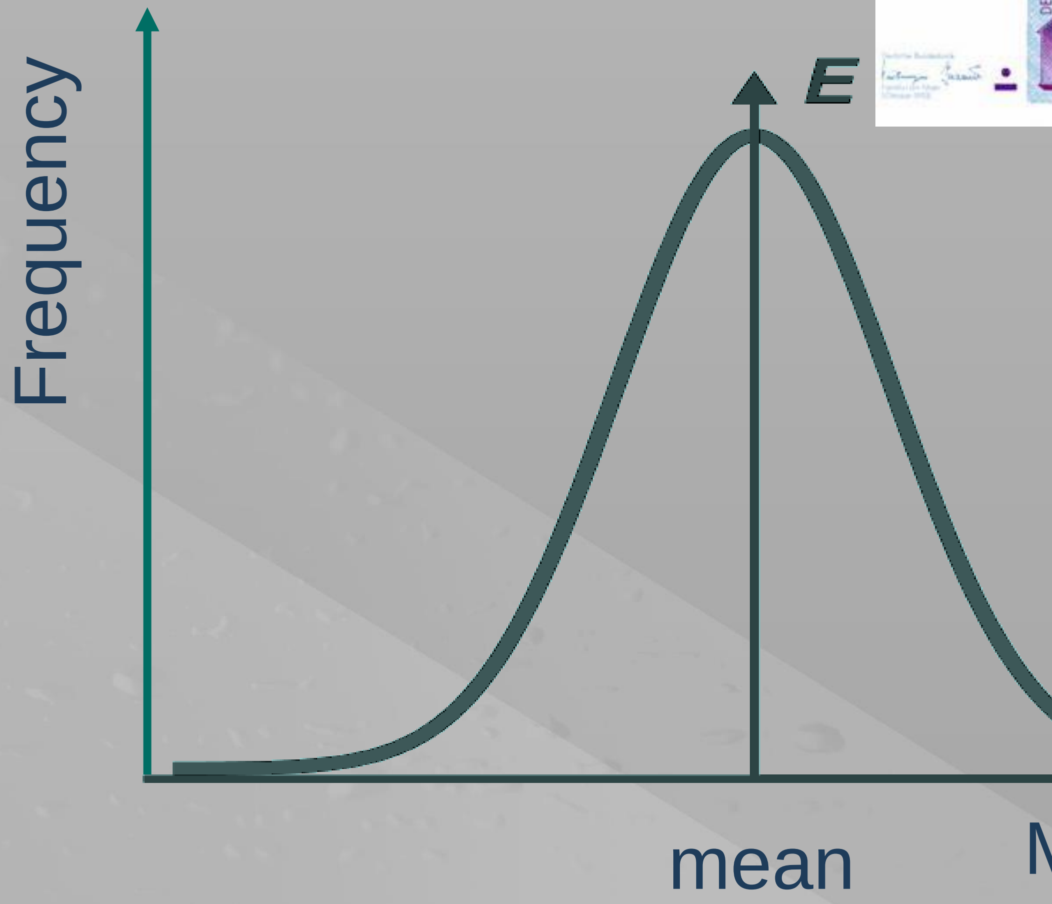
Statistical evaluation of strength

- Only part of the population is tested – **random sample**
- From the results of random sample can be estimated a corresponding parameter of the population
- Typical population has **normal distribution** (Gaussian function)

Normal distribution

- for the whole population



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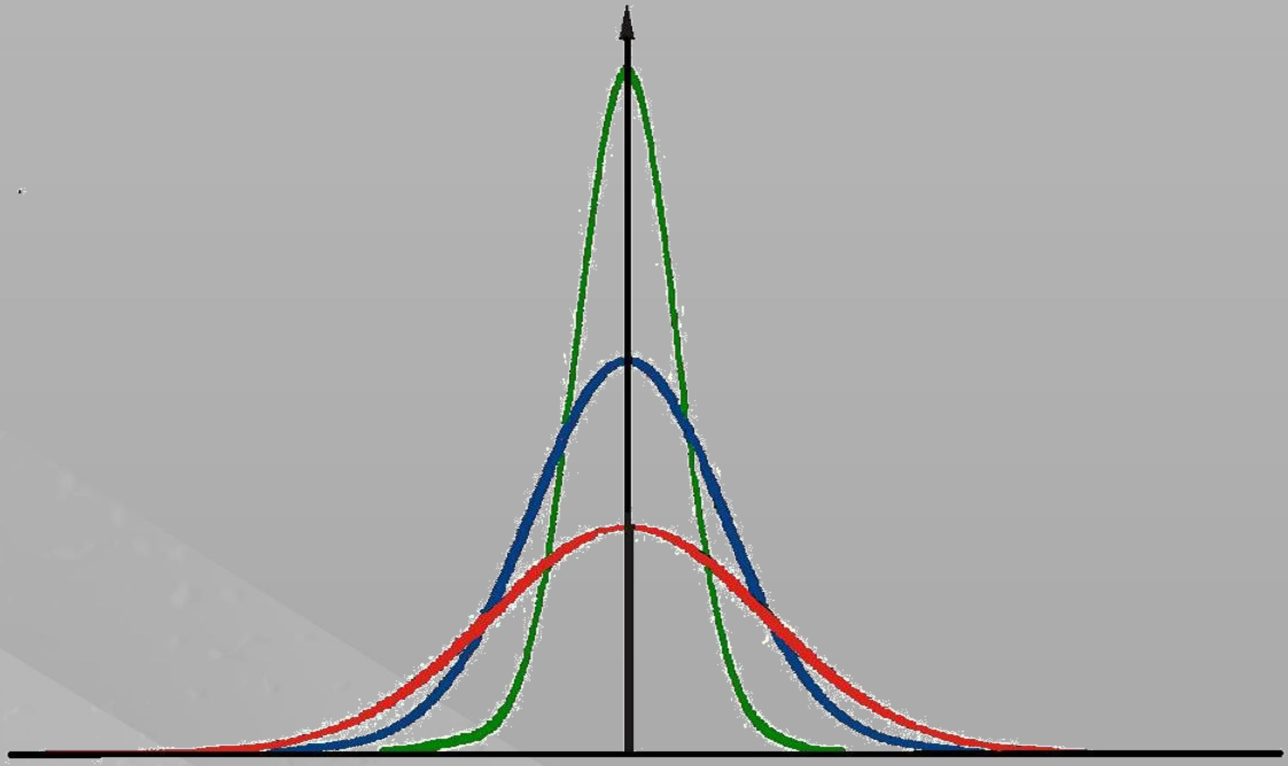
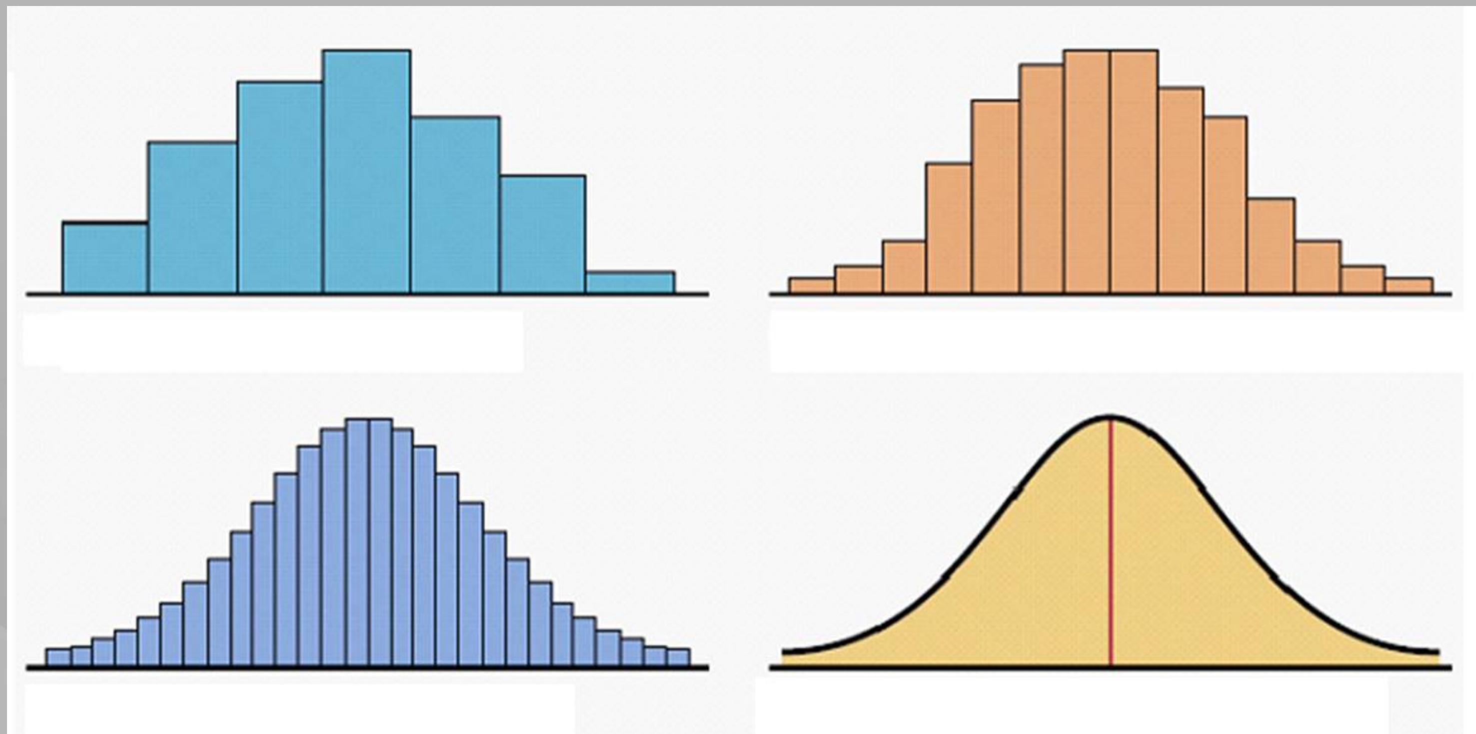
Gaussian curve



- the narrower and higher the curve is, the more statistically homogenous the data

Histograme



- from testing of random sample the distribution curve could not be made
- the more numerous the random sample is, the closer to the curve the histogram is

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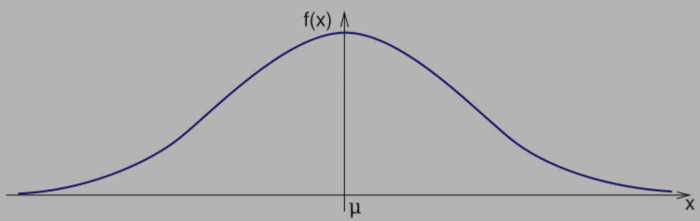
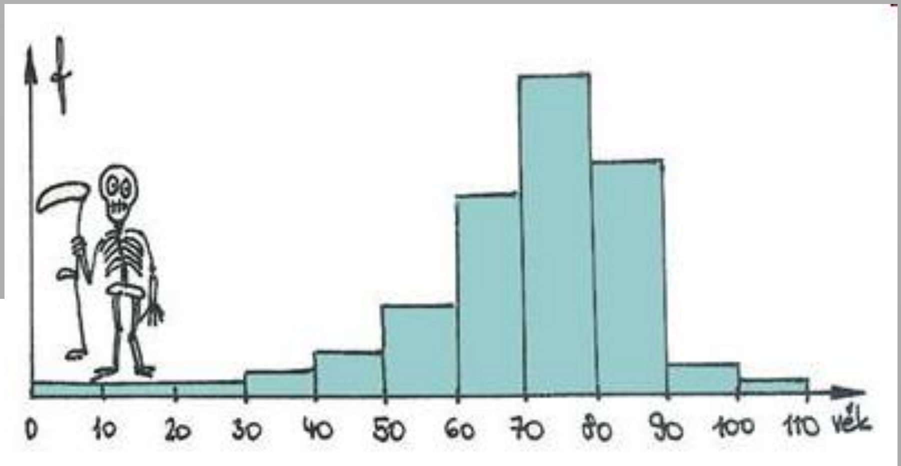
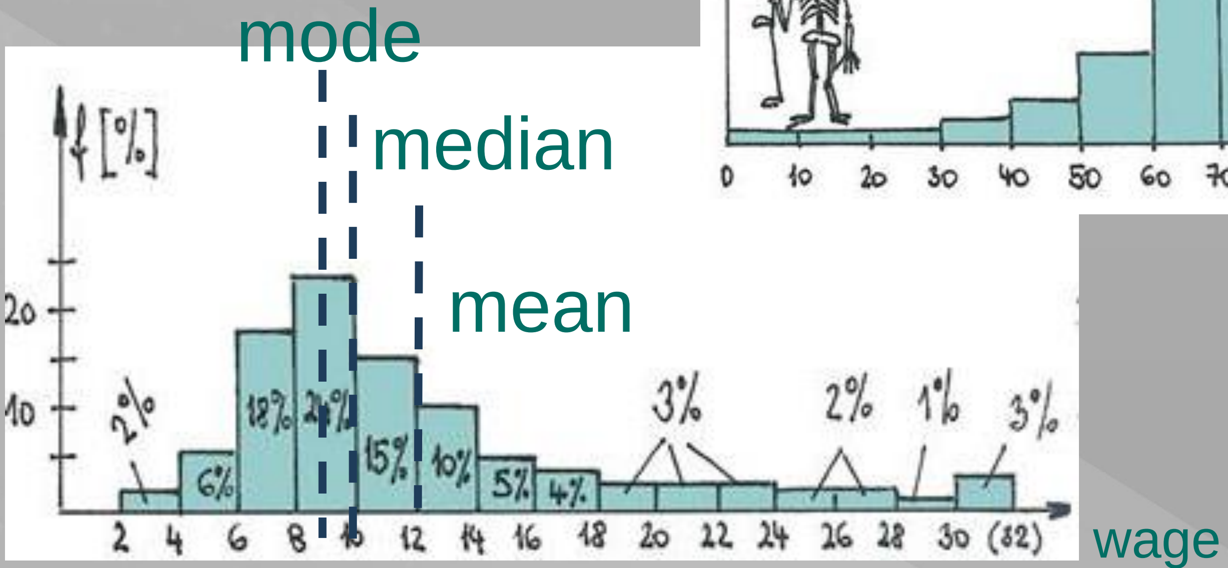
Normal and other distribution

- normal distribution
- non-symmetrical







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Statistical parameters

Values:	4, 8, 6	2, 5,11
• **Mean**	$\bar{x} = 6$	$\bar{x} = 6$
Deviations	-2,+2, 0	-4,-1,+5
Sum of deviations	0	0
Deviations square	4, 4, 0	16, 1, 25
Sum of squares	8	42
• **Variance**	**2.67**	**14**
• **Standard deviation**	**1.63**	**3.74**

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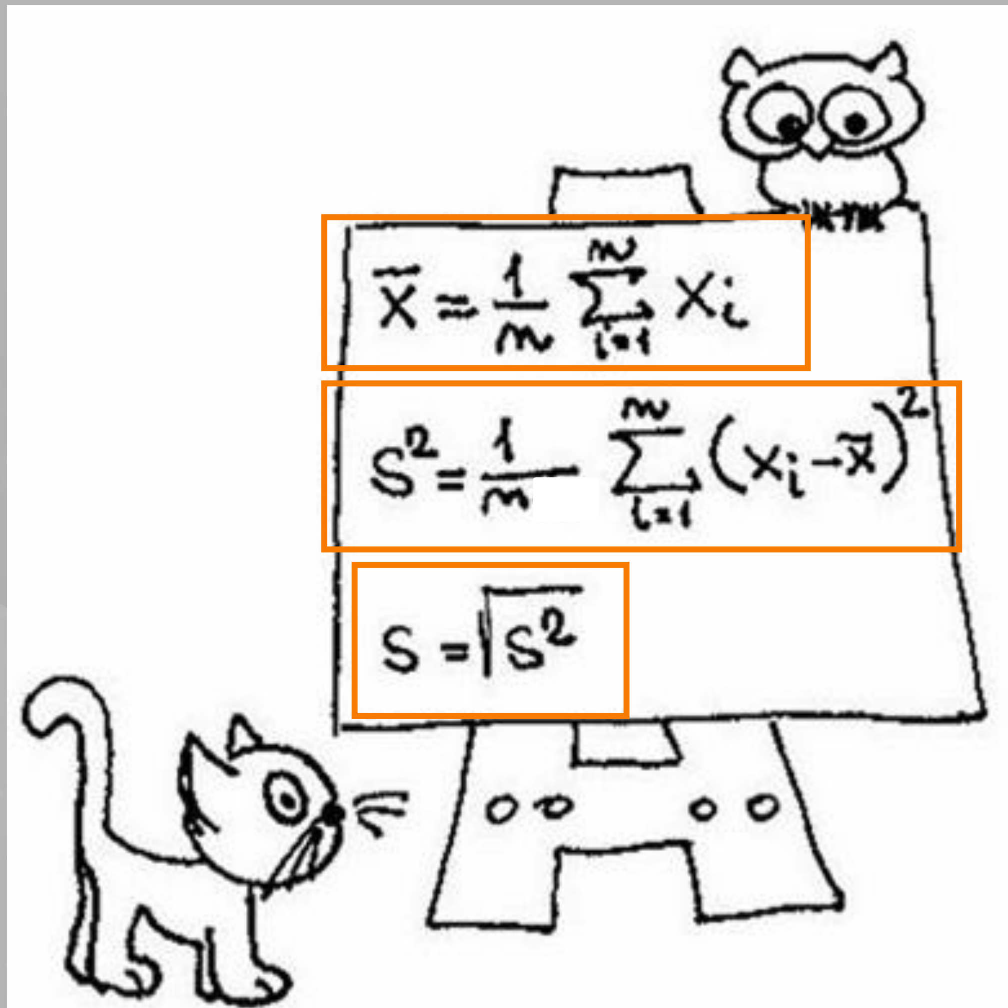
Statistical parameters



mean

variance

standard deviation

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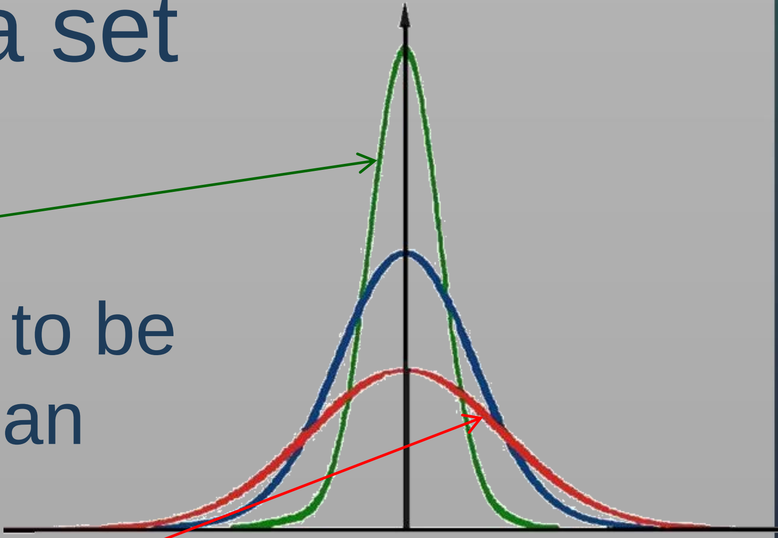
Standard deviation s

- **measure of variability or diversity** of a data set

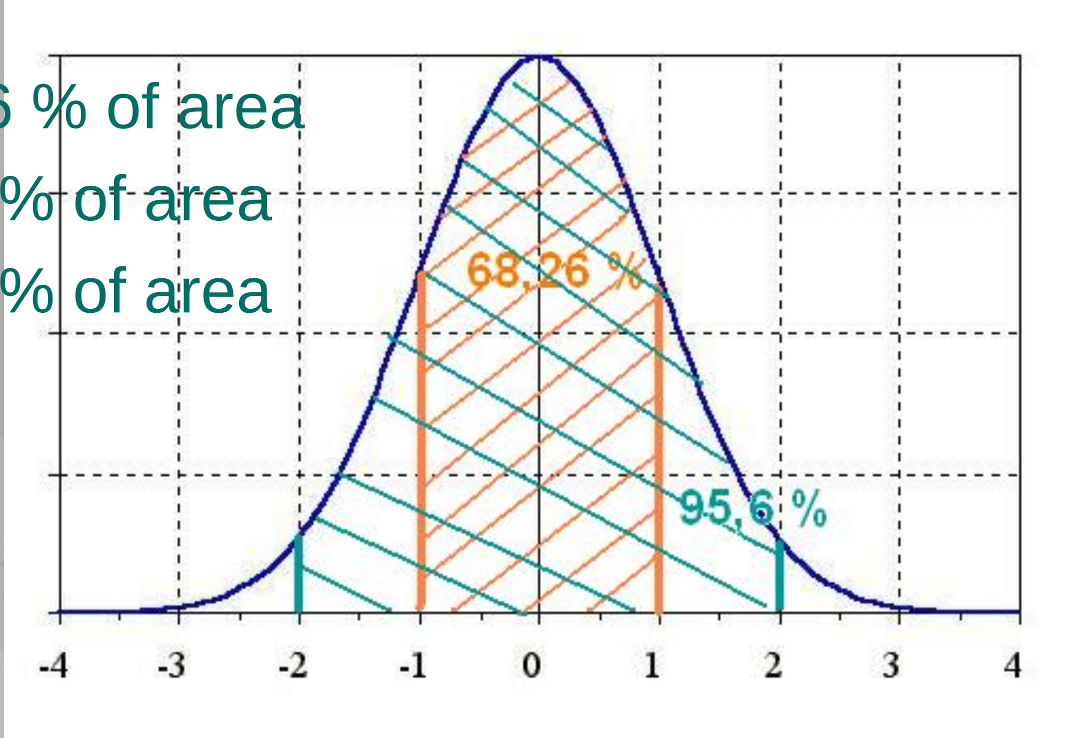


- low standard deviation
  - the data points tend to be very close to the mean
- high standard deviation
  - the data points are spread out over a large range of values

Normal distribution

- symetrical

- +s to -s : 68.26 % of area
- +2s to –2s : 95.6 % of area
- +3s to –3s : 99.7 % of area



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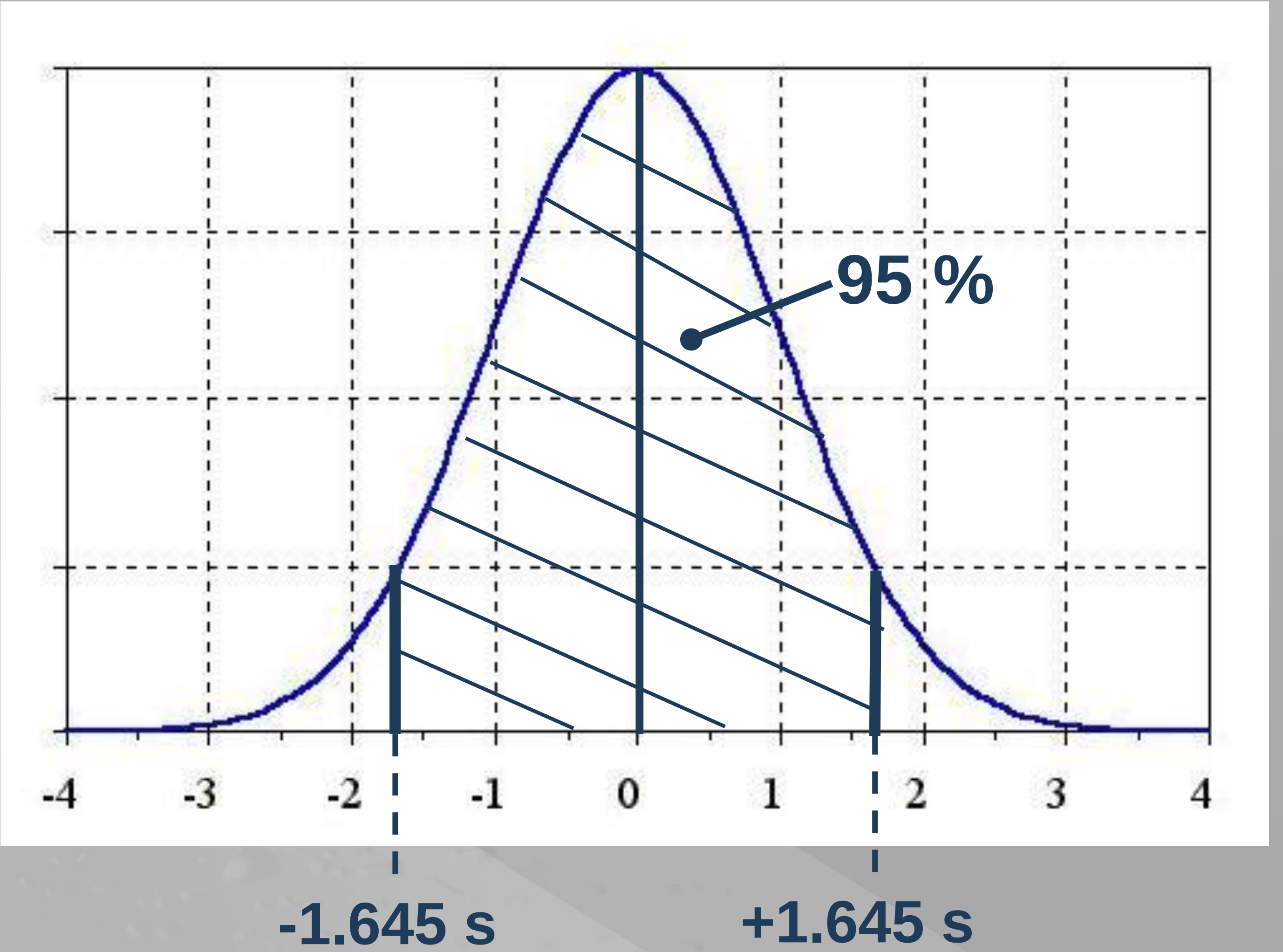
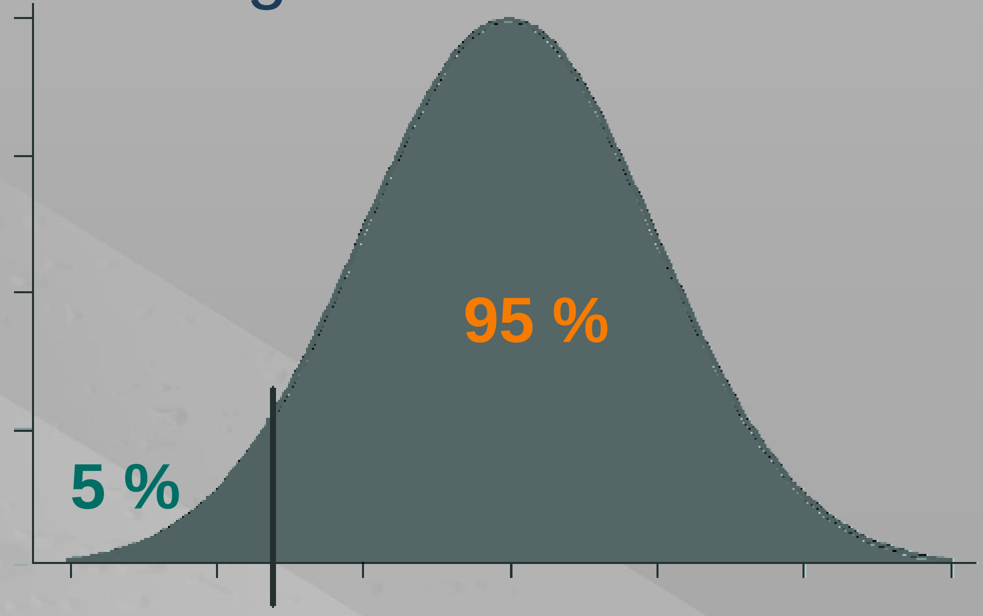
Guaranteed value



Guaranteed strength

- the value of the strength, for which can be statistically guaranteed, that 95 % of whole production will have the same or higher value of the strength



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