Properties of materials

- Basic physical properties
- Hygric and diffusion properties
- Mechanical properties
- Thermal properties
- Acoustic properties
- Radioactivity
- Chemical properties

Basic physical properties

- properties whose determination requires only the measurement of the mass and dimensions (or volume)
  - bulk density
  - matrix density
  - relative density
  - porosity (open, closed, total), pore size distribution
  - granularity, grain size distribution

Bulk density, matrix density

– Density is defined as the ratio of the elementary mass to the elementary volume

– Bulk density – the total volume of a body is considered (including the pores), and

$$\rho = \frac{dm}{dV}$$

- the unit = kg/m^3
- for a homogeneous material the definition is simpler,

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

– Matrix density – the volume <u>without pores</u> is considered

Experimental determination of bulk and matrix density

- Gravimetric method – from the measured dimensions of the sample and its mass, the bulk density can be calculated

- Pycnometric method – used for measurement of the matrix density
  - An indirect method
  - Pycnometer = a special vessel having a stopper with a capillary for the overflowing liquid; hence, the pycnometer volume is constant
  - The matrix density of material is calculated as

$$\rho_{matrix} = \frac{m_1}{m_3 - (m_2 - m_1)} \rho_{water} \qquad (1)$$

  - m_1 = mass of a dry sample
  - m_2 = mass of a closed pycnometer with a sample and water
  - m_3 = mass of pycnometer filled with water
  - The mass difference between the situation [pycnometer + water] and [pycnometer + water + sample] is $m_3 - m_2 = V_{matrix}\,\rho_{water} - V_{matrix}\,\rho_{matrix}$ so that $\rho_{matrix} = m_{matrix} / V_{matrix} = a\,(\rho_{water} - \rho_{matrix})$ with $a = m_1/(m_3 - m_2)$
  - From this relation we get Eq. (1) above

- (building) materials are mostly not homogeneous
  - they are porous, often formed from a mixture of several components

- therefore, the bulk density is used in technical applications for the basic characterization of building materials
  - The bulk density depends on the matrix density of the individual components and on the porosity
  - The bulk density changes due to the moisture content (the porous space can be filled by water)
  - For loose materials (aggregates, sand) and compressible materials (mineral wool, glass wool etc.) also on their compressibility
  - Powder density – involves the whole volume of the grains including the gaps and interspace between the grains

Relative density

- Describes how the material volume is filled with the solid phase (defined only for solids)
- It is the ratio of the solid phase volume V_h to the total volume V = the ratio of the bulk density to the matrix density:

$$h = \frac{V_h}{V} = \frac{\rho_v}{\rho_{mat}}$$

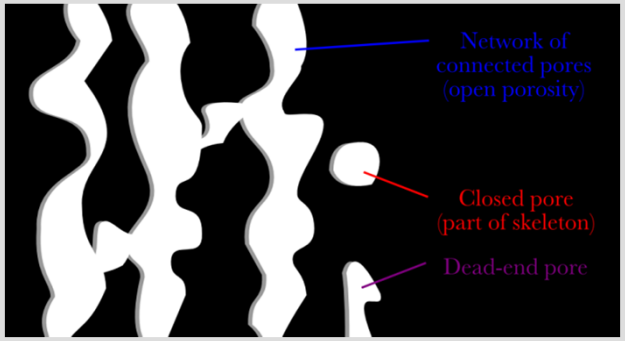
- It is a number between 0 and 1

Porosity

- Porosity is the ratio of the pores volume V_o to the total volume V of a porous body,

$$\psi = \frac{V_o}{V} \qquad [-]$$

- **Open porosity** = the part of the total porosity involving the open pores - pores having a direct connection with the surface of a material



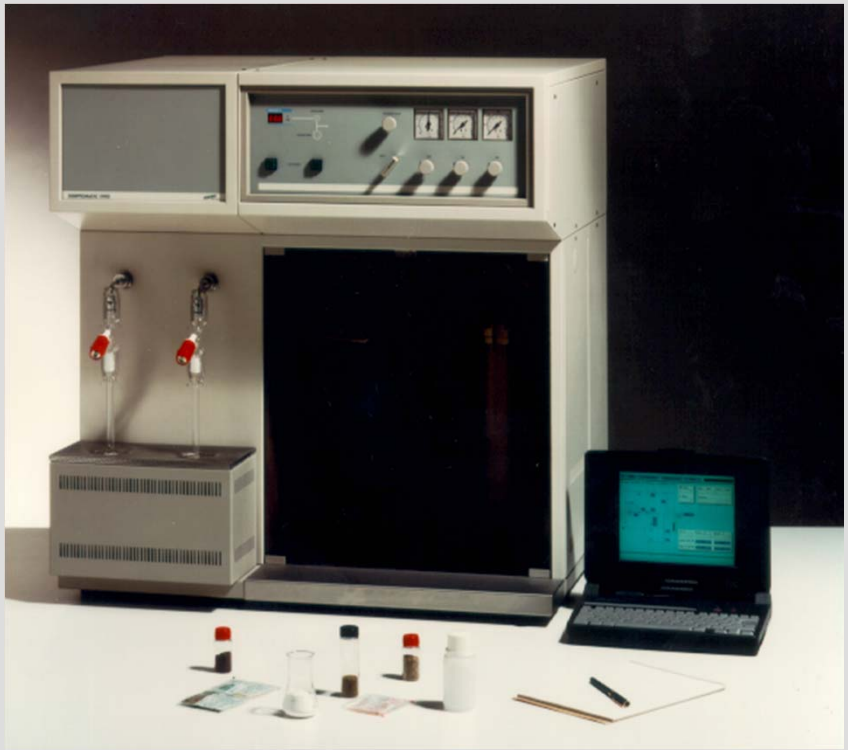
  - Open pores are usually formed by
    - the gases released during the material production (light-weight materials),
    - water evaporation from the materials (concrete, ceramics, plasters, cement based composites)
    - intentional aerating and foaming (light-weight concretes, perlite).

Closed porosity = the part of the total porosity including closed pores (these pores are not connected with the material surface and so do not take part in transport processes)

- the closed pores can be formed e.g. by sintering (of ceramics) and do not allow the air humidity to enter the porous structure
- the pores may have complicated and variable shapes
- therefore, the porosity of materials is described by pores distribution curve which represents the pore sizes
- Different methods and approaches are used to measure the pores distribution curve such as the mercury porosimetry, gas adsorption porosimetry, electron microscopy, optical microscopy, and water suction

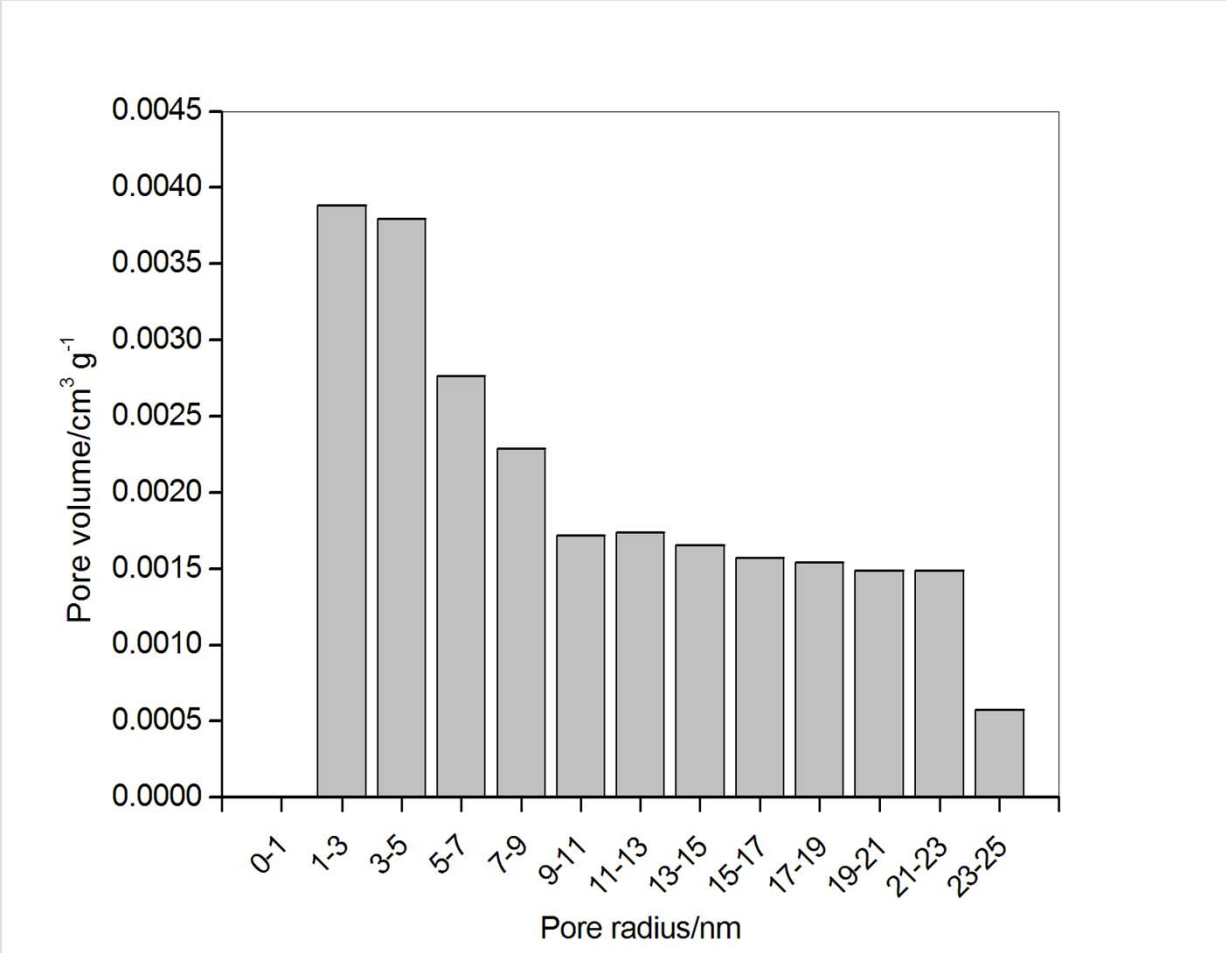
Gas adsorption porosimetry

- Suitable for micro and mesoporous materials (pore radius < 25 nm)
- Uses adsorption of the inert gases (such as helium) that are forced to enter a sample under a given pressure
- From the known gas volume inside the sample and the pressure we can estimate the volume ratio of pores of a given radius



Gas adsorption porosimetry

Mesopores volume distribution of metakaolin:



Mesopores volume:
0.021 $cm^3\ g^{-1}$

Mercury intrusion porosimetry

- Suitable for meso and macroporous matters (pore radius > 2 nm)
- Uses mercury rather than a gas

Material	Porosity [%]
Ceramic brick	20 - 37
Cement mortar	31
Lime mortar	41
Gypsum	51 - 66
Sand	39
Fine aggregates	42
Marble	2 - 3
Sandstone	1 - 31
Limestone	31
Slate	1,5 – 2,5