Laboratory exercise No. 2 – Basic material parameters of porous building materials

Materials (building materials) can be classified according to the different criteria, e.g. based on their properties, function, chemical composition etc. Using these criteria, we can distinguish between following basic groups of materials:

1) inorganic materials – metallic and non-metallic (ceramics, glass, inorganic binders and fillers, mono-crystals, surface coatings)
2) organic materials – fuel, plastics (polymers), paper
3) composite materials – matrix with reinforcement (combination of two or more materials), glass-ceramics, reinforced concrete, glass-cement, carbon fibre based composites.

With respect to the scale of investigation, texture and structure of materials can be distinguished. Texture describes spatial distribution of particles and pores on macroscopic level (from 0.1 mm). Structure characterizes type and composition of particular phase without relation to spatial distribution. This characterization is done typically on microscopic level (<1μm).

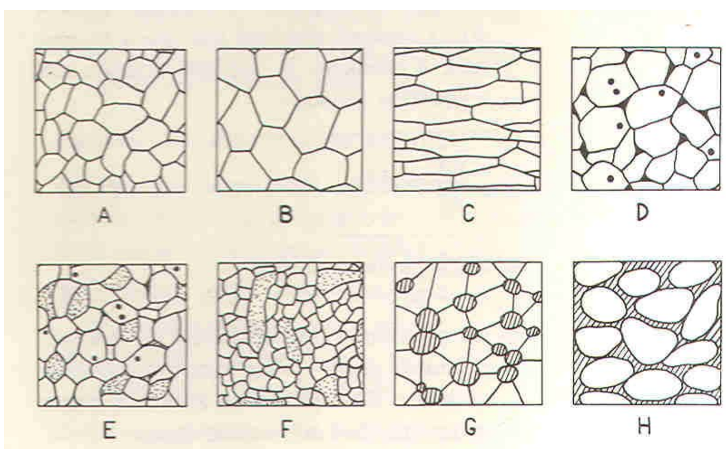

Fig. 1: Idealized microstructures: A) poly-crystallic with grains of different dimension, B) poly-crystallic with grains of similar dimension, C) poly-crystallic with oriented grains (microtexture), D) microstructure with small pores, E) microstructure having pores dimension equal to dimension of grain, F) microstructure with big pores, G) microstructure having two phases –

crystalline and glass (dashed line), H) microstructure of two phases whereas the crystalline phase has not direct bound

Structure of materials is determined by their geometrical characteristics, nominally by volume, porosity, dimension, distribution and shape of pores and by specific surface. The shape of pores can be open, open and connected (concrete, air aerated concrete, bricks) and closed (sintered ceramics, polystyrene, non-liquid-absorbing materials).

Liquid penetration into the open pores of different dimension can be described by the following equation

$$r = \frac{2\gamma}{p\cos\Theta} \Rightarrow r_{Hg} = \frac{1.227}{p} \Rightarrow r_{H_2O} = \frac{0.146}{p},$$

where p is liquid pressure[Pa], Θ wetting angle [°] (water 0°, mercury 140°), γ surface tension [$N.m^{-1}$] (water 0.073 $N.m^{-1}$, mercury 0.47 $N.m^{-1}$).

Pores of building materials are not simple capillaries. Their shape is complex and variable. Therefore the porosity of building materials is described by the pores distribution curve. It is function describing the dimension and volumetric distribution of pores in materials. For its measurement several different methods were developed, e.g. mercury porosimetry, gas adsorption porosimetry, electron and optical microscopy etc. There is also possible to describe porosity by aeration method or by nitrogen absorption using BET method.

The total porosity of material can be calculated according to the following equation

$$Pc = 100 * (1 - \frac{\rho_v}{\rho_{mat}}) \qquad [\%],$$

where ρ_v is bulk density [$kg.m^{-3}$] and ρ_{mat} matrix density of the studied material [$kg.m^{-3}$].

The simplest way how to access the basic material parameters represents gravimetric method. From the measured dimensions of the sample and its mass, the bulk density can be calculated.

$$\rho_v = \frac{m_d}{V} \qquad [kg.m^{-3}].$$

The value of saturation moisture content and the remaining basic material parameters can be measured for example by water vacuum saturation method. From the measured dry mass of sample m_d, mass of fully water saturated sample m_v and from the mass of immersed saturated sample m_a (so-called Archimedes weight) the sample volume can be calculated

$$V = \frac{m_v - m_a}{\rho_l} \qquad [kg.m^{-3}],$$

where ρ_l is density of liquid (water).

Basic material properties as saturation moisture content w_{sat} and material matrix density ρ_{mat} can be determined by the following equation

$$w_{sat} = \Psi_0 \rho_v = \frac{m_v - m_d}{\rho_l} \qquad [kg.m^{-3}],$$

$$\rho_{mat} = \frac{m_d}{V(1-\Psi_0)} \qquad [kg.m^{-3}].$$

where Ψ_0 is total open porosity defined as the ratio of the pores volume to the total volume of material.

Experimental procedure: The studied sample is placed into the vessel for evacuation and the vessel is vacuumed. Then, the vessel is fulfilled by distilled water and vacuumed again. The fully water saturated specimen is then placed on digital scale and its mass m_v and mass under water m_a are measured.

Experimental assessment of volume of un-shapely building materials samples is very difficult. On this account, the indirect pycnometric method is used for the matrix density measurement.

Pycnometer is special vessel having stopper containing capillary for the overflowing liquid. Hence, the pycnometer volume is always the same. The matrix density of material can be then calculated using following equation

$$\rho_{mat} = \frac{m_1}{m_3 - (m_2 - m_1)} \rho_l \qquad [kg.m^{-3}],$$

where m_1 is mass of dry sample [kg], m_2 mass of closed pycnometer with sample and liquid [kg], m_3 mass of pycnometer with stopper fulfilled by liquid [kg], ρ_l density of used liquid [kg.m^{-3}] (for water at 20 °C cca 1 000 kg.m^{-3}).

Not only the total open porosity, but also the dimension and distribution of pores has clear relation to the materials performance within the moisture transport, thermal and mechanical loading. On this account we will deal also with the theoretical assessment of the capillaries radius, what represents certain theoretical simplification of the real porous structure of building materials.

Experimental measurement can be then performed for example by mercury or helium pycnometry (see above).

Using the volumetric water saturation w_{sat} that can be measured by standard laboratory test, the capillary radius r can be theoretically assessed. For demonstration of the practical assessment of capillary radius we choose the cube of dimension 1000 mm fully saturated by water. On the basis of fully water saturation value of the particular material, the volume of capillaries Q_c, and the weight mass of water in capillaries Q_w, can be determined.

The volume of capillaries Q_c can be calculated from equation

$$Q_c = V \frac{w_{sat}}{100},$$

where V [mm^3] is cube volume, w_{sat} water saturation of the material related to the percentage of sample volume.

Weight mass Q_w of the water in capillaries is then given by relation

$$Q_w = Q_c \rho_w,$$

where $\rho_w = 1\ 000$ kg.m^{-3}.

Theoretical length l_c of the set of capillaries is possible to calculate from equation

$$l_c = \frac{Q_w}{F},$$

where F is shear flow and its value is 0.00765 g.mm^{-1}. On the basis of theoretical assumption of free water transport in capillaries, the number of capillaries can be determined using equation

$$n = \frac{l_c}{a_c}.$$

Since we consider for simplicity the water transport into the cubic sample, the parameter ac (parameter of the capillary length) is given for the studied case of cubic sample by relation

$$a_c = \frac{1000}{2} = 500 \qquad \text{[mm]}.$$

The theoretical radius of capillary can be then calculated using formula

$$\frac{Q_c}{n} = \pi r^2 l_c \Rightarrow r = \left(\frac{Q_c}{n \pi l_c} \right)^{\frac{1}{2}}.$$

Tasks of the laboratory exercise No. 2:

Task 1: On gravimetric principle determine bulk density of given materials.

Using digital length meter are measured the dimensions of specimen whereas every size is measured in different place three times. For the volume V calculation, the arithmetic average of measured values is used. For the fully dried samples is then measured their weight m_d. Determine the bulk density ρ of the studied specimens.

Task 2: On the basis of known value of matrix density and measured bulk density (Task 1) calculate the total open porosity of the investigated materials.

Material	**Matrix density ρ_{mat} [kg.m^{-3}]**
Brick	2683
Concrete	2620
Expanded Polystyren	1060
Extruded Polystyren	1050
Hemp Wool	1365
Mineral Wool	2400
Air-Entrained Concrete (porobeton)	2450

Task 3: Determine the matrix density of the tested material using pycnometric method.

The measurement will be performed on three samples of given material.

Task 4: Determine the theoretical radius of capillary of brick masonry and the compressive stress caused by the capillary elevation

Within the laboratory experiment, the saturation moisture content of brick masonry was measured. The laboratory measured value of the fully water saturation w_{sat} is equal to 36 vol.%.

Laboratory protocol:

Front page:	Title of experiment
	Student’s name (or the members of study group)
	Date
Protocol:	Short description of the studied materials
	Description of applied experimental methods
	List of used devices, tools and meters
	Measured values and used constants
	Computational and final results
	Evaluation and data interpretation, conclusions