MATERIALS PHYSICAL PROPERTIES AND TESTS

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1. COMPRESSION TEST

The success of any civil engineering project depends on quality control tests before, during and after construction. The behaviour of material under loading represents the response of the material to an external action. The main purpose of a mechanical test carried out on a specimen is to get properties, such as: compressive, tensile and other strength; modulus of elasticity (E-Young modulus), etc. The strength of material is the limit value (critical value) of a stress σ (τ).

Materials testing to static loads

Axial compression: For this test, prismatic specimens, cubic specimens, cylindrical specimens, etc (figure 1.) are used.

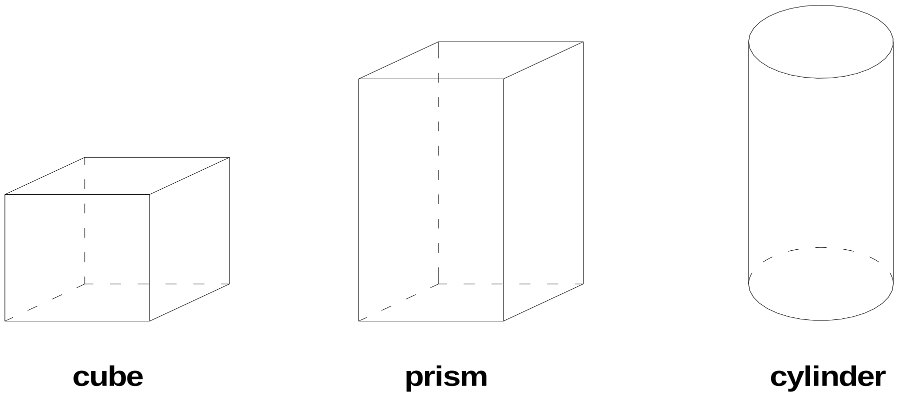


Fig. 1.

For this test compression machines have been designed (figure 2).

Fig. 2. Compression test machine

Compressive strength f_c is obtaining with formula:

$$f_c = \frac{F_{max}}{A} \quad (N/mm^2) \qquad (1.)$$

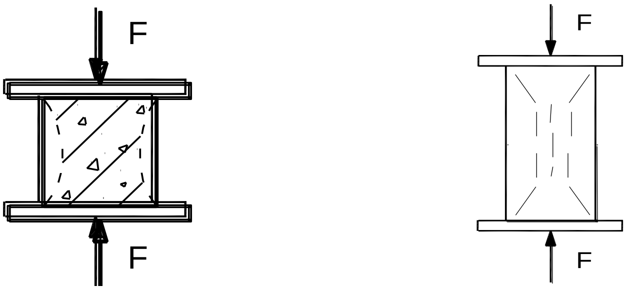
where: F_{max} - maximum load until crush sample, in N;

A - the surface load area, in mm^2.

The result is the average of the resistances obtained on minimum 3 samples.

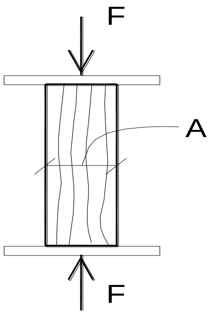
The samples are cleaned and will be placed between the platens of the hydraulic testing machine so that the force direction of testing is perpendicular to placement direction.

In figure 1.3. the compression test on different samples types is shown.



Cubic sample Prismatic sample

Fig. 3.a The compressive strength obtained on concrete sample



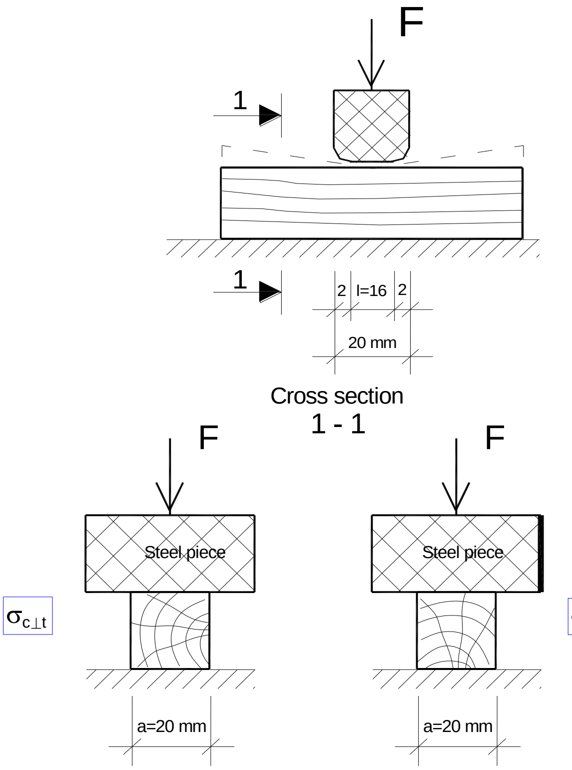
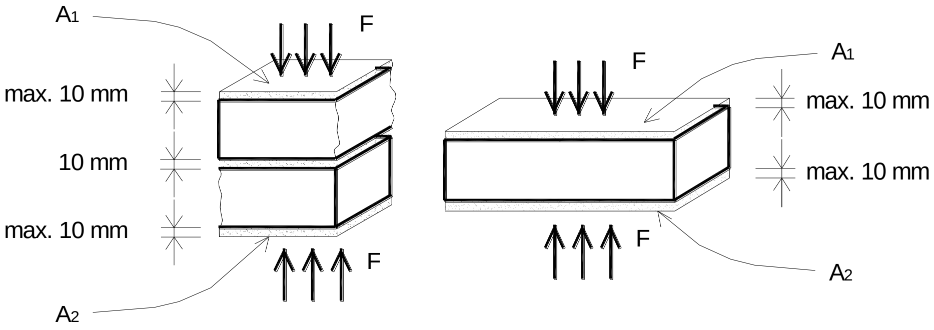


Fig. 3.b The compressive strength obtained on timber sample



Solid brick
(two half brick)

Vertical holes brick
(one entire brick)

Fig. 3.c The compressive strength obtained on brick samples

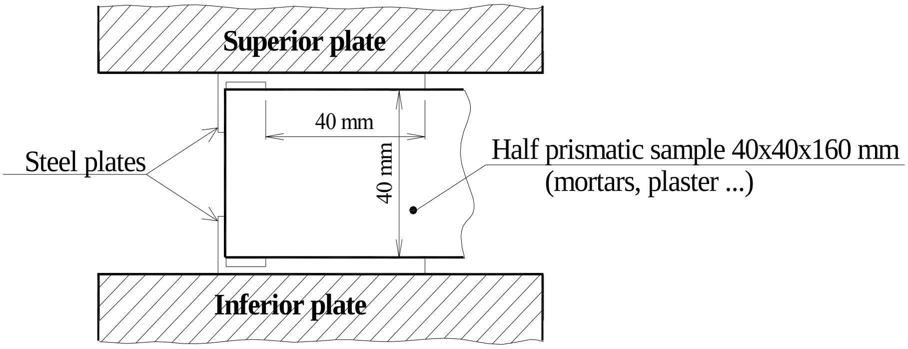


Fig. 3.d The compressive strength obtained on mortar samples

Cube fracture

Cube fracture might be produced without cancelling friction between the machine plates and the cube surfaces in contact with these plates. In such a case, due to friction between the contacting surfaces, the tangential stresses developed at the contacting surfaces prevent the test sample from suffering strain. This fact is responsible for an increment in the cube strength. The fracture of the test specimen is produced by the detachment of its lateral parts following inclined planes at 30^{o} with respect to the vertical; two butt-ended truncated pyramids are thus formed.

Friction between contacting surfaces is usually prevented by applying a paraffin layer, by interposing lead leafs or cardboard, etc. In such a case, transverse swelling of the cube is free to develop over its whole height and fracture takes places due to the cracks being initiated in the direction of compressive stress, as in the case of prismatic specimens. In the latter case, the ultimate strength value is lower than in the preceding case and does not depend on the cube sizes.

Romanian Standard Specifications require that concrete class should be tested with no attempt to prevent friction between contacting surfaces.

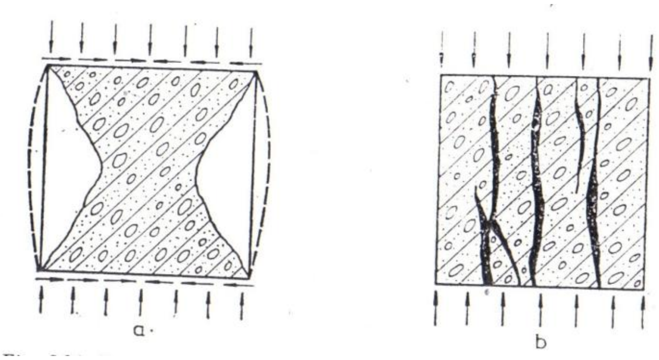


Fig. 4. Fracture patterns for concrete cubic specimens under centric compressive stresses

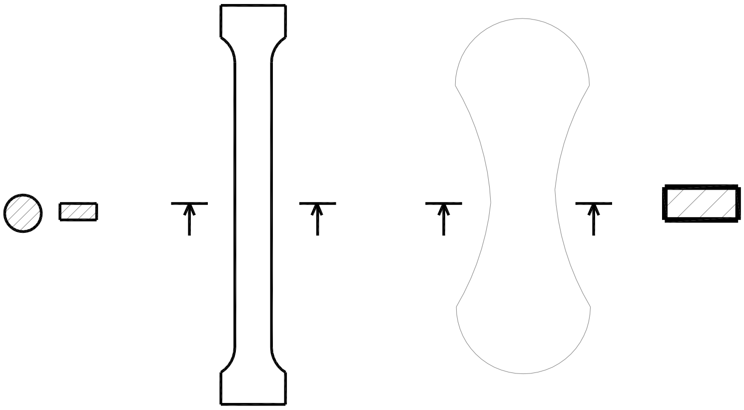
(a) with friction on the contact faces

(b) without friction

Fig. 5. Way of fracture of cubic concrete sample under centric compressive stresses with friction on the contact faces

2. TENSILE TEST

For the tension test there are used specimens with shape as presented in figure 6. The tests should be made by means of a flexural machine.



Steel and polymer samples　　　　Rock (stone) samples

Fig. 6.

The tension strength f_{ct} is obtaining with formula:

$$f_{ct} = \frac{F_{max}}{A} \qquad (N/mm^2) \qquad (2)$$

where: F_{max} - maximum load until crush sample, in N;

A - surface loaded area in the marked zone, in mm^2.

Bending tensile strength (or flexural strength) is determined on prismatic sample like in drawing presented in figure 7.

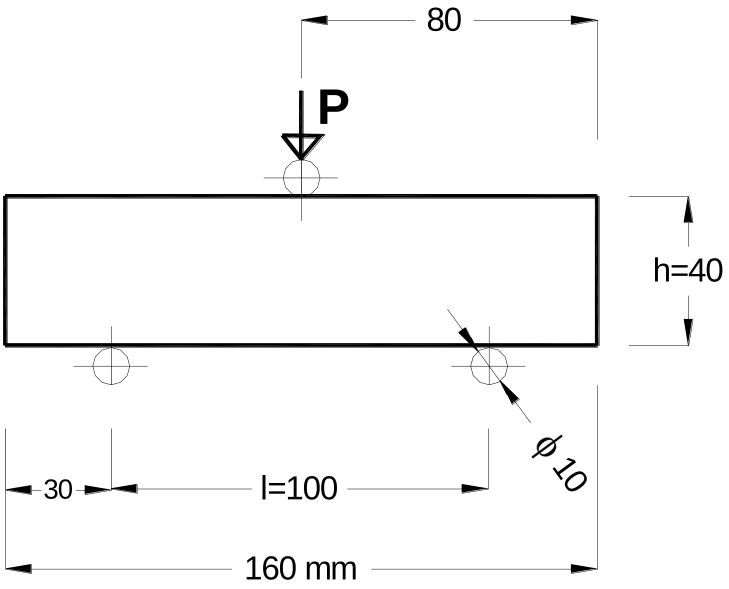


Fig. 7. Bending tensile applied on mortar sample

The bending tensile strength f_{ct} for samples with 40x40x160 mm dimensions is calculated by:

$$f_{ct} = \frac{3}{2}\frac{P \cdot l}{h^3} \qquad [N/mm^2] \qquad (3)$$

where:

P - bending broken force, in N;

l - the span between bearing, in mm;

h - height of prism cross section, in mm.

The final result is the average of the resistances obtained on minimum 3 samples.

Steel tension test

It is the most important determination on building metals. Test is made on special samples with circular or rectangular cross section.

For soft steel a characteristic diagram “stress-strain” is presented in the following figure:

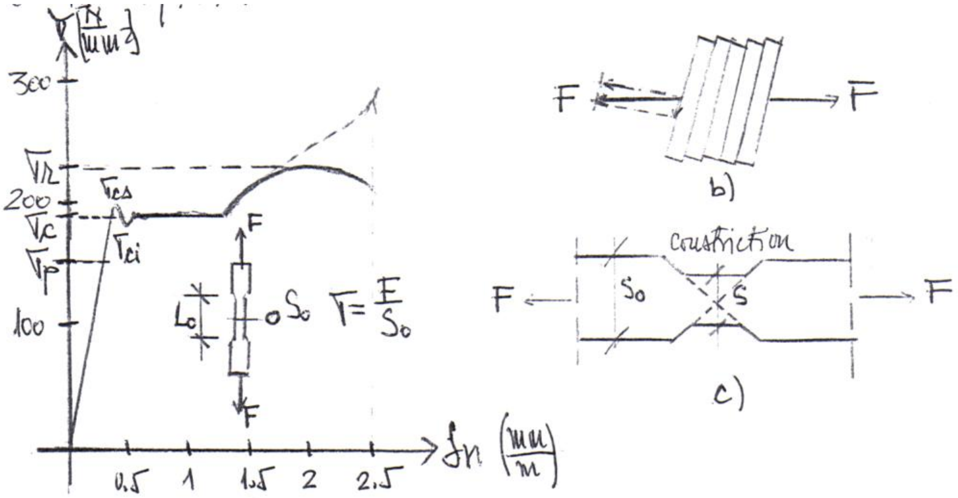


Fig. 8. Characteristic stress-strain diagram for soft steel

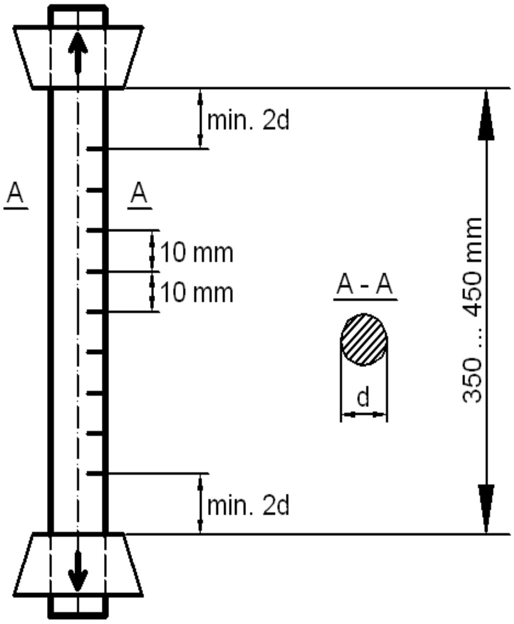


Fig. 9. Tested sample

where:

-σ_p is the limit of proportionality where the stress deviation is under 10%;

- σ_c is the yield limit with extreme vales σ_{cs} and σ_{ci}. From this limit (σ_{ci}), steel has plastic deformations or yield deformations which are produced due to destroy of crystal-lattice planes of steel: a progressive constriction of cross section will result;

-σ_r is the ultimate stress or ultimate tensile strength; from yield limit to ultimate stress a cold-hardening of steel is produced.

3. MATERIALS' VOLUMETRIC MASS

Materials' volumetric mass represents the mass of unit volume and it is quoted in International System in kg/m^3. In the case of building materials, following densities can be established: *real density* ρ; *apparent density* ρ_a; *bulk density* ρ_g; *pile density* ρ_s.

3.1. Density (real)

Real density ρ of a solid material is the ratio between the mass and the real volume of that solid:

$$\rho = \frac{m}{V} \text{ [kg/m}^3\text{]} \tag{4}$$

By *real volume* V, one can understand the volume from which the pores were eliminated. Because building materials have a porosity grade (excepting superior class glass, laminated steel and some polymers), in order to determine the real volume, it is necessary to destroy the structure of the material in order to eliminate all its pores. This can be realised by pulverization of the material in fine particles having dimensions smaller than

0.2 mm (so that the powder will pass through the sieve having 900 eyes/cm^2). The obtained material is homogenized and drayed out in the stove at 105-110 ^{0}C, until between two successive weightings, made at a time interval of 4 hours of drying and 1 hour of cooling, the mass remains constant.

From the obtained material, a mass of m= 2…15 g is weighted and introduced into a graduated cylinder. For materials' real volume determination, a graduated burette is used (fig. 10), which is to be filled up with an inert liquid regarding to the material (such as: water, gasoline, CCl_4 etc). A liquid volume V_b is released from the burette into the graduated cylinder, and then by use of a metallic thin rod, the powder is mixed, so that the air between particles is eliminated and the liquid penetrate the whole powder. The liquid level from the graduated cylinder is denoted by V_c.

The material's real volume is determined by the following relationship:

$$V=V_c-V_b \ [m^3] \qquad (5)$$

Knowing the mass m and the real volume V of the material, the real volume mass will be determined by means of 1.4. relationship.

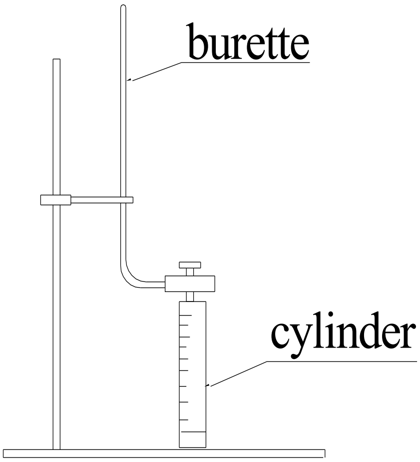


Fig. 10. Device for real density determination

3.2. Apparent Density ρ_a

Apparent density ρ_a represents the ratio between material's mass and its apparent volume V_a (in which the pores are also included):

$$\rho_a = \frac{m}{V_a} \qquad [kg/m^3] \tag{6}$$

$$V_a = V + V_{pores} \qquad [kg/m^3] \tag{7}$$

The mass m is determined by draying out the material, at 105-110 ^{0}C into the specific stove and simply weighting it.

The apparent volume is determined according to the one of the following methods, regarding to the shape of the sample:

Method A. Determination of Apparent volume by Direct Measurement of Samples' Dimensions

This method can be used only for samples that have a regulated, known geometrical shape.

For *apparent volume* determination, the sample is measured in the following way: for cubic and prismatic shapes' like samples (fig. 11) all edges are to be measured a_i, b_i, c_i, where i= 1…4 and mean values are computed such as:

$$a = \frac{1}{4}\sum_{i=1}^{i=4} a_i \tag{8}$$

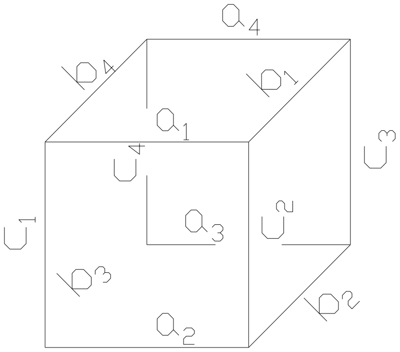


Fig. 11. Cubic sample

For cylindrical samples (fig. 12), two perpendicular diameters are measured at their basis and also to the middle of their height d_i, where
i= 1…6. The four heights h_i, i= 1…4, are also measured:

$$d = \frac{1}{6}\sum_{i=1}^{i=6} d_i \tag{9}$$

$$h = \frac{1}{4}\sum_{i=1}^{i=4} h_i \tag{10}$$

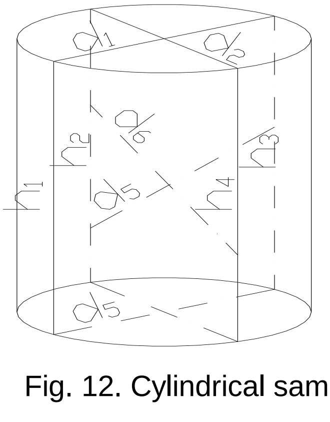


Fig. 12. Cylindrical sample

Having all geometrical dimensions the *apparent volume* of the sample can be obtained.

Method B. Apparent Volume Determination By Measuring The Dislocuated Water Volume

This method is used for irregular shape-like samples. The drayed sample is weighted, than it is covered by a thin paraffined layer, or it is saturated with water. The water saturation is done at normal pressure introducing the sample into distillate water up to ¼ of its height for two hours and then the water level is raised up to ¾ of samples' height, for another 24 hours. After this, the sample is covered by distillate water and kept in this way another 24 hours. At this time end, the sample is rinsed out by a wet piece of cloth; it is weighted and introduced again into the distillate water. The weighting procedure is to be repeated from 24 hours to 24 hours until the weighted masses dose not differ more then 0.05%.

This method is not so accurate because the open pores of the tested sample do not retain the water during the extraction of the sample from the water.

In the case of using the paraffin method, the drayed out sample is weighted, obtaining its mass m, then the sample is immersed into the melted paraffin solution for 1-2 seconds and then it is extracted and cached from another place and again immersed into paraffin. The paraffin coat obtained after cooling does not permit the water to pass into sample's pores. The paraffined sample is weighted, thus obtaining the mass m_1. The difference m_1-m represents the mass of the paraffin layer. Knowing the paraffin density, $\rho_p=0.9$ g/cm^3, the paraffin volume can be determined:

$$V_p = \frac{m_1 - m}{\rho_p} \ [\mathrm{cm}^3] \qquad (11)$$

The apparent volume of the sample is obtained extracting from the apparent volume of the paraffined sample V_1, the volume of the coat of the paraffin V_p:

$$V_a = V_1 - V_p \text{ [cm}^3\text{]} \qquad (12)$$

After preparing the sample by means of one of the upper presented ways, the apparent volume can be established using a graduated cylinder or, for bigger samples, a vessel with a lateral hole.

In the case of small samples with irregular shapes, the determination is made by help of a graduated cylinder of 250-500 cm^3. For this, a liquid volume of V_1 is poured into the graduated cylinder and then, the sample is carefully introduced too.

The water level will rise up to the level V_2 in the graduated cylinder. The rising of water level equals to the apparent volume of the sample, denoted V_a (fig. 13).

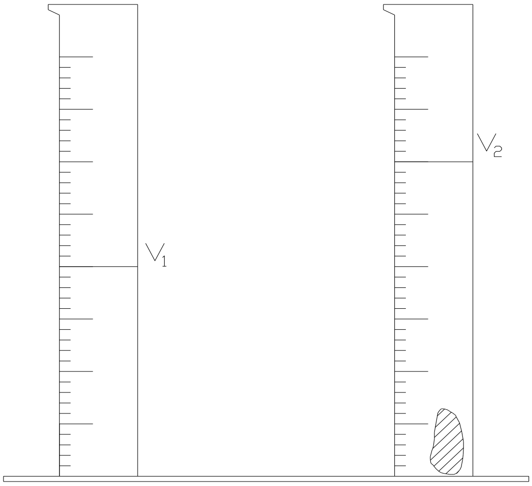


Fig. 13. Graduated cylinder

$$V_a = V_2 - V_1 \text{ [cm}^3\text{]} \qquad (13)$$

For big samples, having irregular shapes, the apparent volume is determined by use of a vessel with a lateral orifice (fig. 14).

For this case, in order to calibrate the determination device, the water is introduced first over the orifice level and the excess water is let to pour through the orifice. Then, the saturated or paraffined sample is immersed carefully into the vessel, the dislocated liquid is collected into a graduated cylinder and represents the apparent volume of the sample (because water density is 1 g/cm^3) (fig. 14).

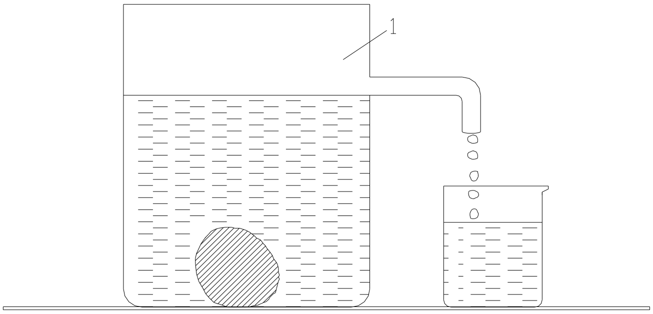


Fig. 14. Lateral orifice vessel

3.3. Bulk Density ρ_g

The bulk density is determined for granular materials (cement, lime, plaster, sand, gravel etc) and represents the ratio between mass of granular material and its bulk volume (which includes its pores volume present in each granule and the volume of free spaces between granules):

$$\rho_g = \frac{m}{V_g} \text{ [kg/m}^3\text{]} \qquad (14)$$

$$V_g = V + V_{pores} + V_{spaces} \qquad (15)$$

For determining the bulk density, cylindrical shaped vessels are used, having a volume of 1 ℓ, for granular materials with ϕ_{max}=8 mm and of 5 ℓ for granular materials having ϕ_{max}=16 mm. The value of bulk density is in function of the compaction grade of the material, so that, it is determined by one of the following states: aerated state and compacted state.

Bulk Density – Aerated State ρ_{ga}

The granular material, previously drayed out, is poured, from 10 cm height with a soffit (5 cm height in the case of hydrated lime), into a vessel which has a known volume (V_g) and mass (m_1). The vessel is fulfilled until a peak of granular material is obtained. The material's peak is levelled up by help of a metallic line, and the vessel is weighted (m_2). *Bulk density in aerated state* is computed by:

$$\rho_{ga} = \frac{m_2 \quad m_1}{V_g} \text{ [kg/m}^3\text{]} \qquad (16)$$

(or kg/dm^3 in the hydrated lime).

Compacted Bulk Density $\rho_{g\hat{\imath}}$

The granular material, previously drayed out, is introduced into a determination vessel of known mass (m_1) and volume, in three successive layers, after each one, the vessel being bitted 50 times by the table, or vibrated on vibrating table for 50 seconds. For compacting of the last layer, a prolong is added to the vessel; after compacting being finished, the prolong is taken away and the filled in vessel is weighted (m_2).

Compacted bulk density is:

$$\rho_{g\hat{\imath}} = \frac{m_2 - m_1}{V_g} \text{ [kg/m}^3\text{]} \qquad (17)$$

3.4. Pile Density ρ_s

The *pile density* is determined for materials which can be stored into piles (bricks, wood etc) with the following relationship:

$$\rho_s = \frac{m}{V_s} \text{ [kg/m}^3\text{]} \qquad (18)$$

where:

m - the material mass, determined by weighting the piles;

V_s - the volume of the pile, determined by mathematical computation by use of piles’ dimensions.

4. COMPACTNESS, POROSITY, WATER ABSORBTION AND HOLES VOLUME

4.1. Compactness represents the filling grade with solid matter of the apparent volume of one material:

$$\%C=(V/V_a)x100=(\rho_a/\rho)x100 \quad (19)$$

Compactness is the ratio between the volume V of the solid phase (actual volume) and the apparent volume V_a.

Because $V \leq V_a \Rightarrow C \leq 100\%$

Materials without pores (glass, steel, some polymers etc) have maximum compactness, that is: C=100%

The compactness is determined (relation 19) by mean of the real and the apparent densities.

Table 1. *Compactness and porosity of some materials*

Material	**ρ [kg/m^3]**	**ρ_a[kg/m^3]**	**C[%]**	**p_t[%]**
Ordinary concrete	2500	2200-2450	88-98	2-12
Autoclaved cellular concrete	2500	300-1200	12-48	52-88
Brick	2500	1000-1800	40-72	28-60
Deciduous wood	1500	800-1000	53-67	33-47
Resinous wood	1500	500-800	33-53	47-67
Steel	7850	7850	100	0
Glass	2600	2600	100	0
Mortars	2500	1500-1800	60-72	28-40

Apparent volume is compound of actual volume V and pores' volume:

$$V_a = V + V_p \Rightarrow V_a \geq V \Rightarrow C \leq 1 \qquad (20)$$

(C=1 for materials without pores)

Compactness influences the materials properties such as: mechanical resistance, permeability, frost resistance etc.

4.2. Porosity represents the unfilling grade with solid matter of an apparent volume of a material. In accordance with the pores' nature, there are two types of porosities: total one and apparent (open) one.

p_t – total porosity is the ratio between total volume of closed and open pores (V_p) and apparent volume of a material (V_a). So, it is the complement of the compactness C.

$$\%p_t = (V_p/V_a)x100 = [(Va-V)/Va]x100 = 100 - \%C \qquad (21)$$

$$\%p_t=(\rho-\rho_a)/\rho=1-\rho_a/\rho \quad (22)$$

$$C+p_t=1 \quad (23)$$

Apparent porosity p_a is the ratio between the volume of opened pores V_{pd} and apparent volume of material V_a. The function of volume p_{av} or p_{am} can be written:

$$\%\ p_{av}=V_{pd}/V_a \quad (24)$$

$$\%\ p_{av}=(V_{pd}/V_a)x100 \quad (25)$$

$$V_{pd}=(m_{sa}-m_{us})/\rho_w \quad (26)$$

where : m_{sa} – saturated mass of sample
m_{us} – dried mass of sample
V_a – apparent volume
ρ_w – water density [1 g/cm^3], 1000 [kg/m^3]

$$p_{am}=V_{pd}/m_{us}\ [m/kg] \quad (27)$$

Practical determination of apparent porosity can be done exactly because opened pores don’t retain water.

From the ratio between p_{av}/p_{am}=>

$$p_{av}=p_{am}x\rho_a=[(m_{sa}-m_{us})/m_{us}]\ x\ (\rho_a/\rho_{us}) \quad (28)$$

Porosity influences in a bad way mechanical properties and in a good way thermal and phonic isolation properties of materials.

4.3. Water absorption represents the property of a material to absorb and keep water into its pores. It is determined experimentally by drying a sample at 105…110 Celsius degrees and than saturating it with water. We know the apparent volume V_a, saturated mass m_{sa} and dried mass m_{us} of a sample.

Function of material's nature saturation process can be done: at usual pressure, at under pressure (20 ml col. H_g), at high pressure (15 N/mm^2) by boiling. Saturated sample is weighed m_{ga}.

Water absorption is obtained as ratio function at volume (a_v) or function of mass (a_m).

$$\%a_v=[(m_{sa}-m_{us})/(V_a X \rho_w)]x100=[(m_{sa}-m_{us})/m_{us}]x(\rho_a/\rho_w)x100 \quad (29)$$

$$\%a_m=[(m_{sa}-m_{us})/m_{us}]x100 \quad (30)$$

where:

m_{us} - drying mass of sample
m_{su} – saturated mass with of sample
V_a – apparent volume
ρ_w – water density
ρ_a – apparent density of sample

$$\% a_v= \%a_m x(\rho_a/\rho_w) \text{ or } a_v=a_m x(\rho_a/\rho_w) \quad (31)$$

Table 2. *Water absorption for ceramic bricks*

Material		**Water absorption a_m (%)**
Full brick	Quality A	8-18
	Quality I&II	8-20
Vertical holes brick	Quality A	Max 16
	Quality I&III	Max 20

4.4. Holes volume represents the characteristic of granular materials (aggregates, plaster, and cement) and it is the total free spaces between granules in unity of volume. It can be determined in a direct method or in an indirect one.

Determination of holes volume with indirect method

If we denote the volume of granular material with V_g and the apparent volume of all granules with V_a =>

$$\%V_{gol}=[(V_g-V_a)/V_g]x\ 100=(1-V_a/V_g)x100=(1-\rho_g/\rho_a)x100 \qquad (32)$$

The holes volume can be established if we know apparent density and bulk density of granular material.

Direct method

It can be used with the aggregates (sand etc.). The aggregate is introduced in a vessel with known volume (V_g). The granulated material is saturated with water if it is a porous material. A known water volume is added (V_w) in order to fill in the holes between granules until the top of the vessel.

The holes' volume can be computed such as:

$$\%\ V_{gol,a} = (1-\rho_{ga}/\rho)x100 \qquad (33)$$

$$\%\ V_{gol,i} = (1-\rho_{gi}/\rho_a)x100 \qquad (34)$$

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