Wydział Inżynierii Lądowej

POLITECHNIKA WARSZAWSKA

BUILDING MATERIALS

SEMESTER II

TECHNICAL PROPERTIES OF NATURAL STONE MATERIALS

Spis treści

1. Purpose of the exercise

The aim of the exercise is to assess the basic technical properties of stone in the light of standard requirements and to indicate its potential use in construction.

2. Basic terms

2.1 Introduction

Hard rock (cohesive rock) – a natural collection of one or a few minerals, which is a fragment of a rock massif (rock body)

Structure of a rock – a collection of recognizable characteristic properties for each rock, which are its mineral composition, its structure and texture

a) mineral composition – main minerals (rock-forming), characteristic for a given type of origin,

b) structure of a rock – a collection of properties defining the type of formation, size and form and way of co-occurrence of rock-forming constituents. We distinguish, among others, the following structures:

- crystalline (coarse-crystalline, medium-crystalline, fine-crystalline, aphanitic, even-crystalline, heterocrystalline)
- porphyritic
- grained (coarse-grained, medium-grained, fine-grained, non-grained, hetero-grained),
- vitreous

c) texture of a rock – spatial positioning (arrangement) and way of filling with rock-forming constituents of rock mass. We distinguish, among others, the following textures:

- condensed
- porous (e.g. micro-porous, cellular, cavity-like, vesicular, spongy)
- almond-like
- chaotic
- ordered (e.g. layer, shale, round)

A rock in air-dry state – a rock of normal humidity, given as a percentage of the mass of water in it, at air humidity of 65-70%

A rock saturated with water – a rock saturated with water to constant mass at normal atmospheric pressure, at room temperature

A rock after examining frost resistance – a rock saturated with water after the completion of examination of frost resistance.

Division (origin) of rocks

Igneous rocks (endogenic) – rocks formed through solidification or crystallization of magma,

a) intrusive igneous rocks – rocks formed through solidification and crystallization of magma inside the earth crust

b) extrusive igneous rocks – rocks formed through solidification of magma on the surface of the earth or close to it

Sedimentary rocks (exogenic) – rocks formed as a result of sedimentation of rock mineral or organic clasters in water or on the surface of the earth, sometimes precipitated from mineral solutions,

c) clastic sedimentary rocks – hard rocks formed as a result of natural accumulation and secondary binding of mineral and rock clasters

d) sedimentary rocks of organic origin – rocks formed mainly through accumulation of calcite or silicate shells and skeletons of animals or plants

e) sedimentary rocks of chemical origin – rocks formed through sedimentation of mineral constituents, precipitated from aqueous solution

Metamorphic rocks – rocks formed though a metamorphosis of magmatic or sedimentary rocks, i.e. the change in their primary structure and mineral composition under the influence of change of physical-chemical conditions (e.g. temperature and pressure) and through addition of other constituents also.

Chosen types of rocks

Intrusive igneous rocks

Granite – a rock of chaotic, condensed texture, main components: quartz, potassium feldspars, acidic plagioclases and mica

Syenite – a rock of chaotic, condensed texture, main components: potassium feldspars, acidic plagioclases, amphiboles, biotites, pyroxenes, small quantities of quartz sometimes

Diorite – a rock of chaotic, condensed texture, main components: plagioclases, amphiboles, biotites and pyroxenes, and sometimes quartz

Gabbro – a rock of chaotic, condensed texture, main components: plagioclases, pyroxene, hornblende, also often olivines

Extrusive igneous rocks

Porphyry – a rock of porphyritic structure, of condensed texture, main components: acidic plagioclase, alkaline feldspars, amphiboles and in quartz porphyry also quartz

Andesite – a rock of porphyritic structure and chaotic, condensed texture, main components: plagioclases, amphiboles and pyroxenes

Diabase – igneous rock of crystalline structure, of chaotic, condensed texture, main components: alkaline plagioclase, pyroxene, also often olivines

Basalt – a rock of aphanitic, fine-grained or porphyritic structure, of chaotic condensed texture, main components: alkaline plagioclase, pyroxene, olivines and iron oxides

Melaphyry – a rock of porphyritic structure, of chaotic condensed, spongy or almond-like texture, main components: plagioclase, pyroxene, olivines, iron and magnesium oxides

Clastic sedimentary hard rocks
Sandstone – a rock of grained structure, of chaotic or arranged texture, condensed or porous, main components: grains of quartz held together by cement (silica, silty, carbonate, ferruginous or mixed)
Greywacke – a rock of grained structure and chaotic texture, containing many clasters of rock

Clastic sedimentary detached rocks.
This group comprises sands, gravels, all-in aggregates, used for mortars and concretes and clays – for ceramic ware

Sedimentary rocks of organic origin
Limestone – a rock of diversified structure, e.g. grained, crystalline, claster-like and of condensed, porous, chaotic, arranged texture, main mineral component: calcite
Dolomite – a rock of most frequently crystalline structure and of condensed or porous, chaotic texture. Main mineral component: dolomite (calcium-magnesium carbonate)

Sedimentary rocks of chemical origin
Travertine – a rock of aphanitic structure and cavity-like texture, condensed or porous, chaotic sometimes. Of similar character may be some cavity-like organogenic calcites, main component: calcite (calcium carbonate)
Bed rock – a sedimentary rock of biochemogenic structure, porous, condensed texture, main components: calcite, silica
alabaster – a rock of crystalline structure and of condensed, chaotic or arranged texture, main component: gypsum (dihydrate gypsum sulfate)

2.2 Division of rocks according to their physical-mechanical properties

according to PN-B01080:1984 “Stone for building and road building – Division and use according to physical-mechanical properties”

According to apparent (volumetric) density

a) very light – of apparent density up to 1500 kg/m^3
b) light - of apparent density from 1500 to 1800 kg/m^3
c) medium heavy - of apparent density from 1800 to 2200 kg/m^3
d) heavy - of apparent density from 2200 to 2600 kg/m^3
e) very heavy - of apparent density over 2600 kg/m^3

According to absorbability

a) very little absorbable – of absorbability below 0.5%
b) slightly absorbable – of absorbability from 0.5% to 5%
c) medium absorbable – of absorbability from 5 to 20%
d) very absorbable – of absorbability over 20%

According to compression resistance

Division of rocks according to its compression resistance

rocks of compression resistance	compression resistance of rocks		
	in air-dry state	saturated with water	after examination of frost resistance
	MPa		
Very small	Below 15	Below 12	Below 10
Small	16-60	12-50	10-45
Medium	61-120	51-100	46-80
Large	121-200	101-190	81-180
Very large	over 200	over 190	over 180

According to grindability (on Boehme wheel)

Division of rocks according to grindability

rocks of grindability	on Boehme wheel	
	in air-dry state	saturated with water
	mm	
Very small	Below 2.5	Below 5.0
Small	2.5-5.0	5.0-7.5
Medium	5.3-7.5	7.6-10.0
Large	7.6-10.0	10.1-15.0
Very large	over 16.0	over 15.0

According to frost resistance

Depending on the number of cycles of freezing and defrosting, after which there is damage to the surface, edges or corners, the following rocks of different frost resistance are distinguished:

a) poor – after fewer than 15 cycles
b) satisfactory – after 15 cycles
c) good – after 21 cycles
d) very good – after 25 cycles

According to the possibility of obtaining polish

Depending on the possibility of obtaining polish, the following rocks are distinguished:

a) polishable
b) non-polishable

According to the resistance of rocks to the detrimental influence of industrial atmosphere

a) fully resistant – rocks not damaged in a fiercely aggressive environment (of SO_2 content from 10 to 200 mg/m^3)

b) moderately resistant – rocks not damaged in the aggressive environment (of SO_2 content from 0.5 to 10 mg/m^3)

c) slightly resistant – rocks not damaged in a slightly aggressive or not aggressive environment (of SO2 content up to 0.5 mg/m3)

3. The course of the exercise

I. Read the procedure for the specified tests (3.1-3.8) and:
- perform the test according to points 3.1-3.4;
- perform the calculations in point 3.5;
- complete table 2.

II. Classify the tested stone material (point 4) in the light of standard requirements (point 2)

III. Develop (e.g. based on access to an internet search engine) examples of the use of stone materials in construction

IV. Determine (taking into account the search results in task 1) external influences (functional, environmental) during the use of a given stone material / product in a given construction application

V. Assign the key technical features of the stone material for a given application, taking into account the environmental impacts (utility, environment) on this material during its operation period

3.1 Apparent density of a regular-shaped sample

Calculated using the direct method for regular shaped samples. The dimensions of the samples are determined in millimeters, mm and the density (V) is calculated, and the mass (m) in grams, g. Apparent density is determined according to the formula below and is expressed in kg / m3 (with an accuracy of 1 kg / m3) or g / cm3 (with an accuracy of 0.001 g / cm3).

ρp = m / V

3.2 Apparent density of aggregate

3.2.1 Materials and equipment to be used

- A sample of the material with an irregular shape,
- Laboratory scale,
- Measuring cylinder.

3.2.2 Test procedure

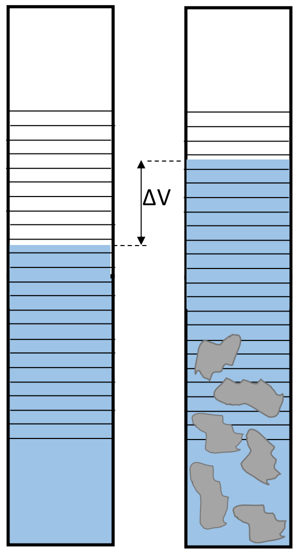
In the case of an irregularly shaped sample, the volume is determined by the hydrostatic method. The sample is saturated to constant weight and then weighed in air and water. Another, less accurate, method is to determine the sample volume in the measuring cylinder. To make this measurement, fill the cylinder with water to a certain level, e.g. halfway, and then place a water-saturated sample in it and read the difference in liquid levels. The apparent density of the material is calculated with an accuracy of 0.001 g / cm3 from the formula:

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

where:

m – mass of a dry sample [g],

V – volume of the sample (including porosity) [cm^3].



Rys.1. The course of testing the volume of a sample with an irregular shape

3.3 Bulk density of aggregate
3.3.1 Materials and equipment to be used
- Sample of granular material,
- Laboratory balance,
- A cylindrical container with a specific volume (1, 2, 5, 10 dm3),
- Correctly long scraper.

3.3.2 Test procedure

The determination consists in examining the quotient of the uncompressed mass of dry aggregate filling a specific container to the volume of this container. The dry mass of the aggregates filling a specific container is determined by weighing and the corresponding loose bulk density is calculated. Aggregate should be dried at temperature (110 ± 5) ° C to constant weight. The weight of each sample should be between 120% and 150% of the weight needed to fill the container. Weigh an empty, dry and clean container (mass m1), place it on a horizontal surface and fill it with aggregate using a bucket until it is poured. When filling the bin, minimize grain segregation by resting the bucket on the top edge. In no case should the edge of the bucket be more than 50 mm from the edge of the bucket. Carefully remove any excess aggregate above the top of the container, making sure the surface is even. Use a scraper to level the surface, taking care not to compress the surface. Weigh the filled container and record its weight (m2). The loose bulk density ρ_nl is calculated with an accuracy of 0.001 g / cm3 from the formula:

$$\rho_{nl} = \frac{m_1 - m_2}{V}$$

gdzie:
m_1 – mass of the measuring container [g],
m_2 – the mass of the container filled with the sample [g],
V– volume of the measuring container [cm^3].

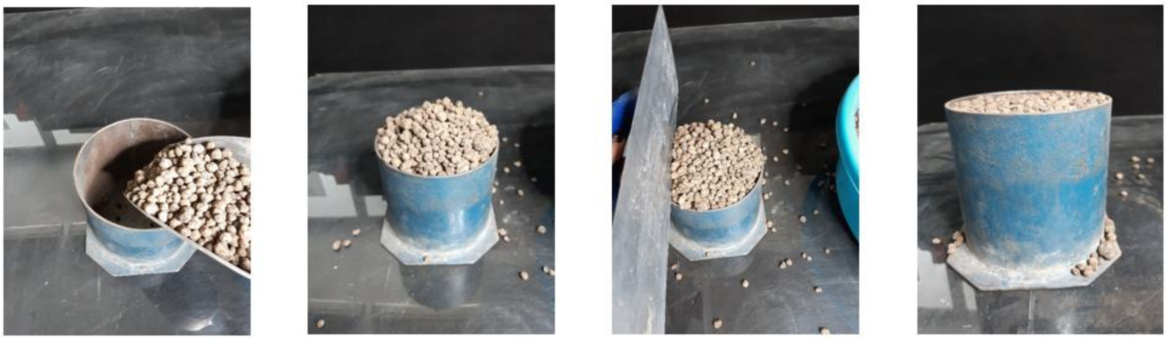


Fig2. The course of the examination of the bulk density

3.4 Aggregate water absorption

3.4.1 Materials and equipment to be used

-Sample of soaked material,

- Laboratory balance,

- Paper towel.

3.4.2 Test procedure

It is the ability of absorbing water by a given material. The term "water absorption" means the total saturation of a given material with water. Two terms can be distinguished: *weight absorption* (N_w) and *volume absorption* (N_o). *Weight absorption* is determined on the basis of the ratio of mass of absorbed water to the mass of the sample in a dry state.

$$N_w = \frac{m_n - m_s}{m_s} \cdot 100\ [\%]$$

m_s – the mass of a sample in a dry state

m_n – the mass of a sample in a state saturated with water.

Volume absorption is calculated according to the formula

$$N_o = \frac{m_n - m_s}{V} \cdot 100\ [\%]$$

V –volume of the sample

3.5 Mohs hardness

Hardness is the resistance of a material to deformation, lasting under the influence of concentrated forces acting on its surface. The mineral hardness scale characterizes the scratch resistance of materials that are harder than that of softer ones - the minerals are set from the softest to the hardest. Each mineral can scratch the mineral preceding it on the scale (softer) and can be scratched by the one following on the scale (harder).

Tabl. 1 Mohs scale - a list of reference minerals and description of the test results

Hardness	Reference mineral	Test result
1	Talc ($Mg_3Si_4O_{10}(OH)_2$)	mineral can be scratched easily with a fingernail
2	Gypsum ($CaSO_4 \cdot 2H_2O$)	mineral can be scratched with a fingernail
3	Calcite ($CaCO_3$)	mineral can be scratched easily with a copper wire
4	Fluorite (CaF_2)	mineral can be scratched easily with a knife edge
5	Apatite ($Ca_5(PO_4)_3(OH$-,Cl-,F-)	mineral can be scratched with difficulty with a knife blade
6	Orthoclase ($KAlSi_3O_8$)	the mineral can be scratched with tool steel
7	Quartz (SiO_2)	scratches glass
8	Topaz ($Al_2SiO_4(OH$-,F-$)_2$)	scratches glass with ease
9	Corundum (Al_2O_3)	cuts glass, can be scratched with diamond
10	Diamond (C)	scratches corundum, it can only be scratched by another diamond

3.6 Grindability

Determination of grindability of stone materials is conducted on the Boehme wheel (fig. 2) according to PN-B04111:1984.

Fig.2. Boehme wheel for determining grindability of stone materials

From the solid of stone, one cuts out cubic samples of the side dimension of 71±1mm, and then dries them at the temperature of 105^0C. Each dried sample is measured with the precision of up to 0.01g.
The sample should be placed firmly in the clamp of the machine and loaded with the force of 300N.
The surface of the wheel on the whole length of the grinding strip should be covered evenly with 20g of aloxite powder. After pouring the powder, set the wheel in motion. During the motion of the wheel, the powder should be continuously wiped onto the grinding strip. After every 22 rotations, the wheel should be stopped and the ground material with the powder should be swept away. Then another 20g of the grinding powder should be poured on the wheel in the strip of grinding the sample and the wheel should be set in motion. After every 110 rotations of the wheel, the sample should be taken from the clamp and rotated by 90^0 around its vertical axis in relation to its previous position. After 440 rotations of the wheel, one should measure the height of the sample with a slide caliper with the precision of up to 0.1mm and weigh the sample with the precision of up to 0.01g.
If the rock has very high grindability, after grinding up to 10mm of the sample, one should use straps in order to keep the starting height of the cube.

Calculating the results of determination of grindability

a) on the basis of the loss of height, the grindability of a stone material S should be calculated in mm with the precision of up to 0.1mm as the difference before the examination and after the examination of the average height of the sample, calculated from the arithmetical average of heights measured in mm according to the formula

$$S = \frac{K_1 + K_2 + K_3 + K_4}{4}$$

where:
K_1, K_2, K_3, K_4 – the differences of sample height, measured along perpendicular planes to the assumed base

b) on the basis of loss of mass. Grindability of a stone material S should be calculated in mm with the precision of up to 0.1mm according to the formula

$$S = \frac{M}{F} \cdot \frac{1}{\varsigma_p}$$

where:
M – the loss of mass of the sample after 440 rotations of the wheel, g,
F – the surface of the sample subject to grinding, mm^2,
ς_p – apparent density of the sample , g/cm^3.

An example for calculations (readings are given by the tutor): Test result on Boehme wheel: K_1 = mm, K_2= mm, K_3 = mm, K_4 = mm

3.7 Frost resistence

Determination of frost resistance for stone materials is conducted using the direct method according to PN-B04102:1995.

Shape and dimensions of sample – like when determining apparent density.

3.7.1 Test procedure

Samples saturated with water to constant mass and weighed with the precision of up to 0.1g should be placed in a tank made of wire mesh so that they do not touch one another and then everything should be placed in the freezer. The samples should stay in the freezer for 4 hours until the moment of obtaining in it the temperature of $-20\pm^{0}C$. After that time, the samples with the tank should be moved from the freezer to a vessel with water at room temperature and they should be left totally immersed for at least 4 hours but they should not be taken out of water until the temperature of water reaches $20\pm5^{0}C$. Then the samples should be placed once again in the freezer and frozen and then they should be once again defrosted in water in the same conditions and during the same time as at the first occasion. Freezing and defrosting is one cycle of the examination.

The number of cycles should be adjusted to the examined material and to the requirements of the relevant norm (10-25 cycles).

After each cycle, each sample should be placed on a dry surface and examined. Using a magnifying glass and a needle, one should check the condition of the sample and all observed changes (e.g. cracks, fracturing, delaminations or rounding of edges and corners) should be written down. After the foreseen number of cycles of examination, the samples should be rinsed with water, delicately dried with a linen cloth and weighed with the precision of up to 0.1g.

The measure of frost resistance of the examined stone material is:

a) observation of changes on the samples with the description of these changes, quoting the number of cycles after which they occurred (separately for each sample),

b) the loss of mass (U) of particular samples, calculated as a percentage according to the formula:

$$U = \frac{m_0 - m_n}{m_0} \cdot 100 \quad [\%],$$

where:

m_o – the mass of a sample saturated with water before beginning the examination, g

m_n – the mass of a sample saturated with water after n cycles of freezing and defrosting, g

c) the coefficient of frost resistance (w_z), defining the change of compression resistance, which can only be tested on regular samples and can only be determined in the case where samples do not exhibit any changes in appearance after the examination. Samples saturated with water should then be subject to an examination of compression resistance and the coefficient (w_z) should be calculated with the precision of up to 0.01g according to the formula

$$w_z = \frac{R_z}{R_n}$$

where:
R_z – compression resistance of a sample saturated with water after the examination of frost resistance, [MPa]
R_n – compression resistance of an unfrozen comparative sample, which remained in water during the whole examination of frost resistance, [MPa]

As the final result when determining the mass loss (U) and the coefficient of frost resistance (w_z) one should take, in case of natural homogenous stone materials, the arithmetical average of three measurements, and for heterogeneous ones – of five measurements. In case one observes that the result of the examination of one sample varies from the average by more than 20%, one should neglect such a result, calculate the arithmetical average of the other results and take it as the final result.

3.8 Compression strength

The determination is conducted according to PN-B04110:1984. Depending on the state of the sample used for the determination and the requirements of the relevant norms, the method of determination comprises the following:

a) determination of compression resistance of cubic and cylindrical samples in air-dry state,
b) determination of compression resistance of cubic or cylindrical samples saturated with water,
c) determination of compression resistance of cubic or cylindrical samples saturated with water after the completion of determination of frost resistance using the method of direct freezing and defrosting,
d) calculation of the coefficient of decrease in resistance after saturation with water (softening coefficient),
e) calculation of the coefficient of decrease in resistance after the examination of frost resistance (coefficient of resistance to freezing)

Shape and dimensions of samples:

- a cubic sample of the dimension of the side 50±3mm,
- a cylindrical sample of h =□= 50±3mm,
- an abscised cylindrical sample of the core of the hole of h = □, from 135÷160mm

A sample is compressed in a hydraulic press until it is damaged.
Compression resistance is calculated according to the formula:

$$R_c = \frac{P_n}{F} \cdot 10 \quad [MPa] \text{ (N/mm}^2\text{)}$$

where:
P_n – the largest compressing force, kN
F – area of the surface compressed, cm^2

4. Summary of research results

The evaluation of the research material (Table 3) should be performed on the basis of the results of tests and calculations as well as the criteria included in pkr. 3.7.

Tabl. 2 Test result evaluation

A. Type, structure, mineralogical composition			
1. Type of rock			
2. Place of occurance			
3. Rock structure, structure, texture			
4. Mineralogical composition			
B. Technical features, test results, requirements, analysis of the results			
Type of test	Test result	Requirement	Evaluation
1. apparent (volumetric) density, kg/m^3			
2. Water absorbability, %			
3. compression resistance, MPa			
4. grindability on Boehme wheel, cm			
5. Frost resistance, number of cycles			
6. Possibility of obtaining polish			
7. Resistance to the influence of industrial atmosphere (content of SO_2, mg/m^3)			

5. Scope of the exercise report

The report should include the following points:

I. Subject of research (basic information about tested materials / products)

II. Findings (the results of the determinations obtained during the laboratory classes are presented in tables and compiled as indicated)

III. Conclusions (bulleted statements formulated on the basis of the obtained results)

IV. Literature (references to the literature used to prepare the report)