Warsaw University of Technology

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BUILDING MATERIALS

LABORATORY TASK

Building mortars composition determination

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1. Aim of the task

Introduction to the classification and test methods of mortars, as well as making a qualitative selection and experimental determination of composition (by mass and volume) per 1 m^3 of mortar - developing a recipe for volume and mass mortar.

2. Theoretical background

2.1.Definitions (PN-90/B-14501)

- **Ordinary mortar** - a mixture of at least one inorganic binder, aggregates and sometimes also admixtures and/or additives used for general construction works;
- **Mortar class** (formerly "mortar mark") - a letter and number symbol classifying mortar in terms of its compressive strength, e.g. M 4; the number after the letter M indicates the average compressive strength of the mortar after 28 days;
- **Fresh mortar** – the mortar completely mixed and ready for use;
- **Plastering mortar** – a mixture of at least one inorganic binder, aggregates, and sometimes also admixtures and/or additives, used for external and internal plasters;
- **Masonry mortar** – a mixture of at least one inorganic binder, aggregates, and sometimes also admixtures and/or additives, designed for laying, joining products (e.g. bricks, blocks) in the wall;
- **Binder** – a material used to connect solid particles into a homogeneous, coherent mass, eg. cement, building lime;
- **Aggregate** – a granular material that does not participate in the mortar curing reaction;
- **Admixture** – material added in small quantities to obtain special properties;
- **Additive** – finely divided inorganic material that can be added to the mortar to improve individual properties.

2.2.Introduction

Mortars are divided into ordinary and special modified mortars and due to the bulk density into:

- ordinary mortars (bulk density: $\rho_o \geq 1300\ \mathrm{kg/m^3}$)
- lightweight mortars (bulk density: $\rho_o < 1300\ \mathrm{kg/m^3}$).

The ordinary mortars are defined in PN-90/B-14501 as mortars made on the construction site using traditional methods. Their volume density is from 1700 to 2000 kg/m^3, they are used as masonry or plastering purposes, and depending on the type of binder used, they are divided into:

- Cement (C)
- Lime (W)
- Gypsum (G)
- Cement-Lime (CW)
- Gypsum-Lime (GW)
- Cement-Clay. (CGL)

Special mortars are modified by the most numerous group of building mortars. Due to their use in construction, they are divided into:

- Masonry
- Plaster
- For reconstruction and renovation
- For injections
- Chemically-resistant
- Fire-resistant
- For substrates and flooring
- Other.

The special mortar group also includes modified ordinary mortars, factory-made and available in the form of ready-mixed dry mixtures and liquid as expeditions.

Plaster mortars are used for external and internal plasters. The purpose of plasters is to protect the building against various external and internal factors: atmospheric, environmental, biological and mechanical. Plasters consist of successive layers of mortar applied to the surface, such as:

- **Rough coat/layer (O – from Polish *obrztka*)** – obtained by applying a layer of mortar up to 5 mm thick on the ground; renderings are not leveled to increase the adhesion of the next layer of plaster;
- **Overhead coat/layer (N – from Polish *narzut*)** – a mortar layer 1.0 to 1.5 cm thick; can be applied in two layers of similar thickness;
- **Smooth coat/layer (G – from Polish *gładź*)** – the last, top layer of plaster made of mortar or plaster.

Table 1 presents the scope of mortar tests that relate to the physical and mechanical properties of fresh and hardened mortars.

Table 1. Tests of mortars

No	Tested property	
	Fresh mortar	**Hardened mortar**
1	Volumetric efficiency	Flexural strength
2	Consistency	Compressive strength
3	Plasticity	Tensile strength
4	Volumetric density	Water absorption
5	Time to maintain working properties	Moisture (water content)
6	Ability to hold water	Volumetric density
7	Susceptibility to spontaneous release of water	Capillary rising of water
8	Susceptibility to delamination	Freeze-thaw resistance
9	Air content	Shrinkage (hardrening)
10		Shrinkage (hardrening)
11		Softening coefficient
12		Adhesion to substrate

Classification according to mechanical strength

Construction purpose mortars are also classified in terms of strength. The samples used for testing the flexural strength of mortars are "beams" with dimensions of 40 x 40 x 160 mm (analogous to specimens used in the cement compressive strength test). A set of at least 3 specimens is tested each time. Each of the specimen is subjected to a flexural strength test (static system: a simply supported beam loaded with a concentrated force in the middle of the span). The compressive strength test shall be carried out on the beam halves remaining after the flexural strength test. The beam halves are placed between steel washers and subjected to axial compression in a hydraulic press. The result of the determination is the arithmetic average of at least six measurements.

Based on the average compressive strength of the mortar, it is divided into classes marked with a letter and number symbol - e.g. M 4, where M designation of the compressive strength class, and 4 is the average compressive strength of the mortar, expressed in MPa.

Procedure of determination of building mortar composition

Determining the qualitative and quantitative composition of building mortars is carried out in subsequent stages. In the first stage, assumptions are made regarding the purpose and properties of fresh and hardened mortar. In the second stage, qualitative selection of mortar components is performed and their basic tests are carried out. In the third stage, the amounts of components are determined experimentally and the volume and mass composition per 1 m^3 of mortar is determined. When determining the composition of mortars, use data from Tables 1-5. When determining the composition of plaster mortars, use data from Table 6.

Table 1. Types, classes and consistencies of traditional mortars depending on the purpose according to the standard PN-90/B-14501

No	Purpose of the mortar		Type	Consistency*	Class
1	**For foundations**	**No limit**	C	6÷8	M 4÷M 12
2		**In wetlands**	CGL	6÷8	M 4÷M 7
3			W CW	6÷8	M 0,6÷M 1
4	**For building walls**	**No limit**	C	6÷8	M 4÷M 12
5		**In dry land, single-story residential or utility buildings and makeshift buildings**	CW	6÷8	M 4÷M 7
6		**Walls with smoke and ventilation ducts made of clay or slag concrete**	CGL	6÷8	M 2÷M 4
7		**Load-bearing overhead walls in buildings up to 2 floors, residential or utility**	CW	6÷8	M 2÷M 4
8		**Filling walls and above-ground load-bearing walls in single-story residential or utility buildings and walls of provisional buildings**	W	6÷8	M 0,3÷M 1
9	**For carrying supporting pillars and walls, arches and vaults exposed to loads**		C CW CGL	6÷8	M 12÷M 20 M 4÷M 7 M 4÷M 7
10	**For building thin-walled vaults with a thickness of ¼ brick and ½ brick**		C	6÷8	M 7÷M 20 M 4÷M 15
11	**For flooring**	**Floors substrates**	C	5÷7	M 12÷M 20
12		**Leveling layer under floors**		4÷6	M 2÷M 7

* tested according to PN-B/04500 (cone method)

Symbols: C – cement, CW – cement-lime, CGL – cement-clay, W – lime, G – gypsum, WG – lime-gypsum

Table 2. Compressive class of masonry mortars PN-EN 998-2

Class	M 1	M 2,5	M 5	M 10	M 15	M 20	M d
Compressive strength [MPa]	1	2,5	5	10	15	20	d

d – compressive strength higher than 20 MPa, declared by the manufacturer as a multiple of 5

Table 3. Volume composition of masonry cement mortars

Cement class	cement : sand (proportion by volume)		
	M12	**M15**	**M20**
32,5	1:3,5	1:3	1:1,5

Table 4. Volume composition of masonry cement-lime mortars

Cement class	cement : lime : sand (proportion by volume)			
	M1	**M2**	**M4**	**M7**
32,5	1:2:9 do 1:2:12 1:1:12	1:0,5:4,5 do 1:1:9	1:1:6	1:0,5:4,5

Table 5. Volume composition of masonry lime mortars

Mortar class	Dry-slacked lime	Lime putty
	lime : sand (proportion by volume)	
M0,3	1:6 do 1:4	1:6,5 do 1:4,5
M0,6	1:1 do 1:2,5	1:2 do 1:6
M1	-	1:1,5

Table 6. Recommended types of plaster mortar sets - composition, consistency and classes according to standard PN-90/B-14501

Plaster layer			**Proportion by volume** (binder 1 : binder 2 : sand)					
O	**N**	**G**	**C** (cement:sand)	**CW** (cem:lime:sand)	**CGL** (cem:clay:sand)	**W** (lime:sand)	**G** (gypsum:sand)	**GW** (gypsum:lime:sand)
EXTERNAL PLASTERS								
M2	M2	M2	1:6					
M4	M4	M4	1:5					
M7	M7		1:4					
M12			1:3 i 1:3,5					
M15			1: 2 i 1:3					
Consistency [cm]*			O	O				
			N	N				
9÷11	6÷9	6÷10	G	G	G			
INTERIAL PLASTERS								
	M0,3					1:3 i 1:4,5		
M0,6	M0,6	M0,6			1:3:12	1:1 do 1:3		
M1	M1	M1		1:2:9 do 1:2:12	1:2:10	1:1,5		1:1,5:4,5
M2	M2	M2		1:0,5:4,5 do 1:1:6	1:1,5:8		1:3	1:0,5:3 do 1:2:4
M4	M4	M4	1:5	1:1:6				
M7	M7	M7	1:4	1:0,5:4,5				
M12			1:3 i 1:3,5					
M15			1:2 i 1:3					
Consistency [cm]*			O	O	O	O	O	O
				N		N	N	
9÷10	6÷9	6÷10	G	G	G		G	G

* tested according to PN-B/04500 (cone method)

Symbols: C – cement, CW – cement-lime, CGL – cement-clay, W – lime, G – gypsum, WG – lime-gypsum

3. Practical tasks

3.1. Qualitative and quantitative selection of building mortars

3.1.1. Materials and equipment

- Novikov apparatus,
- flow table set,
- cement binder,
- lime binder,
- fine natural aggregate – river sand of fraction 0/2 mm,
- scale with an accuracy of 0.01 kg,
- plastic bowls,
- metal spoons,
- metal containers with a capacity of 1 dm^3.

3.1.2. Task completion

The process of qualitative and quantitative determination of the composition of mortars should be carried out according to the following stages:

Stage 1: Determining the preliminary assumptions (Table 7)

The initial assumptions relate to the purpose, type of mortar (cement, lime, gypsum, cement-lime, gypsum-lime, cement-clay), strength class of hardened mortar and consistency of fresh mortar (tested according to cone method).

Table 7. Stage 2 of determining the mortar composition – preliminary assumptions

No	Preliminary asumptions	
1	Purpose of mortar	
2	Type of mortar	
3	Compressive class	
4	Consistency	

Stagee 2: Experimental determination of the amount of components, quality control and components testing (Table 8)

The selection of components consists in the selection of the type of components that will be used to prepare the mortar, taking into account the purpose and the required properties of the hardened mortar. One must select at least one type of binder, the type of aggregate and the maximum grain size and then determine the volume proportions of all dry components and examine their bulk density in a loose state.

Tale.8. Stage 2 of determining the mortar composition – qualitative selection and components bulk density in a loos state

Binder 1	Binder 2	Sand	Binder 1	Water
Components				
Proportions by volume				
Bulk density in a loose state ρ_{nx} [kg/dm^3]				

Stage 3: Experimental determination of the amount of components

Prepare the components for test. For this purpose, assume the volume of one volume part of each component, which will be divisible by 0.05 dm^3 (e.g. 0.15 dm^3; 0.20 dm^3; 0.25 dm^3; 0.30 dm^3; 0.35 dm^3; 0.40 dm^3), assuming that the total volume of all dry components will be equal to 1.5 to 2.0 dm^3, so that the volume of prepared trial mix is sufficient to carry out basic tests of fresh and/or hardened mortar. Then prepare a test mortar by dispensing dry components by volume and water in an amount sufficient to achieve the assumed consistency, tested using:

- Cone-shaped intender in Novikov apparatus according to PN-85/B-04500 (Fig.1) – the measure of mortar consistency is the depth of the cone penetration (average of 3 measurements not differing by more than 1 cm); the test consists in filling the measuring vessel to the indicated level and shaking the vessel 5 times to level the mortar surface; then placing the vessel under the cone of the device, lowering the cone to contact with the mortar, lowering the bar to contact the cone shaft and zeroing the measuring disc; after 10 seconds, the cone blockade is released, which freely sinks into the mortar, leaves the scale rod to contact the cone shaft and reads the result on the measuring disc with an accuracy of 0.1 cm;

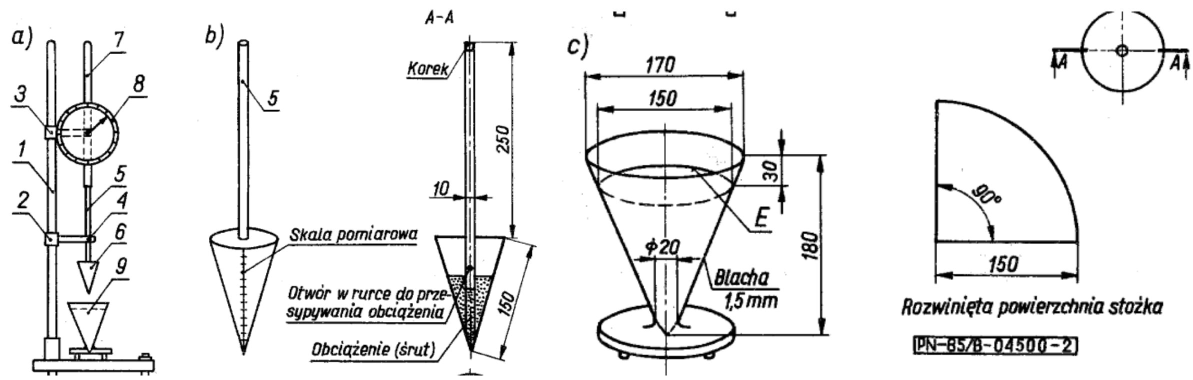

Fig.1. Novikov apparatus with cone-shaped intender used for consistence testing according to cone method described in standard PN-B-04500

- flow table according to standard PN-EN 1015-3 (Fig.2) – the measure of mortar consistency is the average flow diameter of the mortar flowing on the table plate in shape of disc (being the arithmetic mean calculated from measurements taken in two perpendicular directions in cm, with both diameters not differing by more than 10%); the test consists in wetting the surface of the disk and the mold, then placing the mold on the disk and filling it with the tested mortar in two layers, compacted with 10 impacts of the rammer; then excess mortar is cut and its surface is leveled to the edge of the mold, then the mold is raised vertically and the mortar is shaken by turning the crank with a cam within 15 s; finally, with a measuring instrument, measure two perpendicular flow diameters;

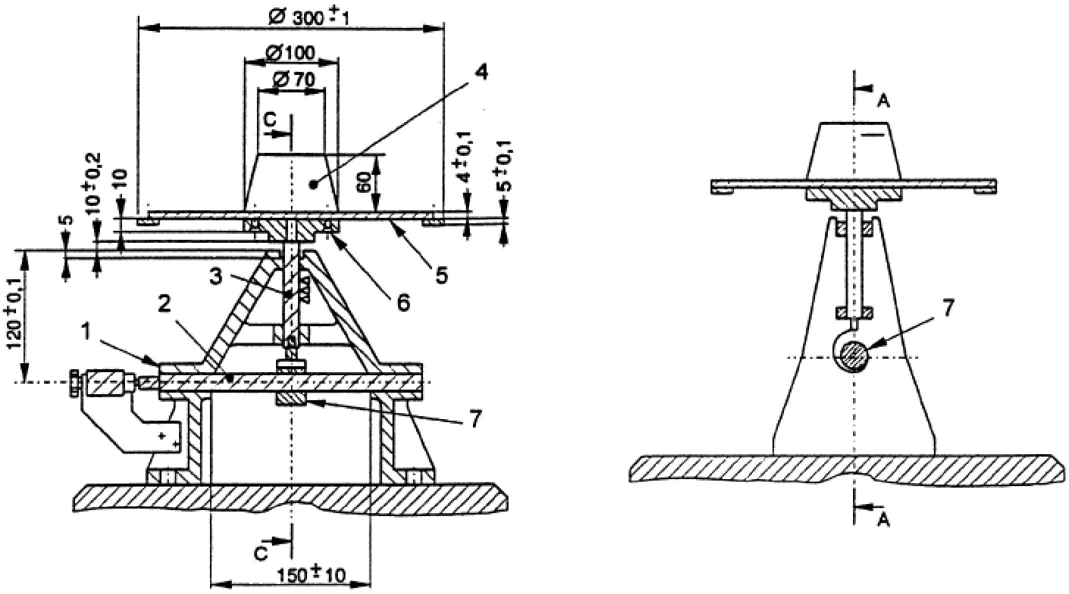

Fig. 2. Flow table according to PN-EN 1015-3 (1 – base, 2 – parallel surface, 3 – the rising element, 4 – mold in shape of cone, 5 – disc table plate, 6 – stabilization of disc plate, 7 – rising mechanism part)

Calculate volumetric density ρ_{oz} according to equation:

$$\rho_{oz} = \frac{m_z}{v_z}$$

where: m_z - mortar mass, being the total mass of components used to make mortar trial mix, v_z - mortar test mix volume.

The experimentally determined volume composition of the mortar should be converted into mass dosing according to the formula:

$$m_x = \rho_{nx} * v_x$$

where: mx - mass of component x for preparation of trial mix, ρ_{nx} - bulk density of component x in loose state, v_x - volume of component x for preparation of trial mix.

Stage 3 of the process of determining the qualitative and quantitative composition of building mortars finishes with determining amounts of components to prepare 1 m^3 of mortar in accordance with the following equations:

$$M_X = m_x * \frac{1000}{v_z} \qquad\qquad V_X = \frac{M_X}{\rho_{nx}}$$

where: M_X – mass of component x per 1 m^3, m_x – mass of component in the trial mix x, v_z – volume of the trial mix, V_X – volume of component x per 1 m^3, ρ_{nx} – bulk density of the component x.

Present the results in table 9.

Table 9. Stage 3 of determining the mortar composition – components quantitative selection, control and testing

<table>
<tr><th rowspan="2">Component</th><th>Binder 1</th><th>Binder 2</th><th>Sand</th><th rowspan="2">Water</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>By volume v_X [dm^3]</td><td></td><td></td><td></td><td></td></tr>
<tr><td>By mass m_x [kg]</td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="5">Fresh mortar properties</th></tr>
<tr><td>Total mass [kg]</td><td></td><td colspan="2">Volume of mortar V_Z [dm^3]</td><td></td></tr>
<tr><td>Volumetric density ρ_{oz} [kg/dm^3]</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Cone method: depth of penetration [cm]</td><td></td><td colspan="2">Flow table method: flow diameter [cm]</td><td></td></tr>
<tr><th colspan="5">Composition per 1 m^3</th></tr>
<tr><th colspan="2">Components</th><th colspan="2">By mass M_X [kg]</th><th>By volume V_X [dm^3]</th></tr>
<tr><td>Binder 1</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Binder 2</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Sand</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">Water</td><td colspan="2"></td><td></td></tr>
</table>

3.1.3. Elaboration of results

Compare the consistency of the prepared mortar, marked using a measuring cone intender, with the consistency assumed in the first design stage.

3.1.4. Assessment of the results

A summary of the process of determining the qualitative and quantitative composition of mortars should be presented in the form of a table - Table 10.

Table 10. Qualitative and quantitative composition of mortars

Mortar type	Mortar class	Proportion of components				Composition per 1 m^3		Consistency		Fresh mortar volumetric density [kg/m^3]
		Cement	Lime	Sand	Water	By mass [kg]	By volume [dm^3]	Cone method [cm]	Flow table method [cm]	
C/CW						C = W = P = W_H =	C = W = P = W_H =			

4. Laboratory report

The laboratory report should include:

I. Subject, aim and scope of research (containing basic information about tested materials/products, test methods, requirements),

II. Tests results with proper units (results obtained in the laboratory prepared in the indicated manner, e.g. put in the proper tables),

III. Conclusions (bulleted statements formulated based on the results obtained),

IV. Bibliography (list of references to the literature or www used to prepare the report).