**Warsaw University of Technology**

Faculty of Civil Engineering

Department of Building Materials Engineering

**BUILDING MATERIALS**

LABORATORY TASK

# Non-hydraulic building binders: Lime binders

Authors:

Joanna Sokołowska, Ph.D.

Kamil Załęgowski, Ph.D.

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# 1. Aim of the task

Introduction to the subject of the types of building lime binders, their properties and test methods.

Performance of the test:

- grinding degree of hydrated air lime (CL S),
- reactivity (time and temperature) during slaking of quicklime (Q).

# 2. Theoretical background

## 2.1. Definitions according to standard PN-EN 459-1:2012:

- **lime** – calcium oxide CaO and/or calcium hydroxide $Ca(OH)_2$ as well as magnesium oxide MgO and/or magnesium hydroxide $Mg(OH)_2$, produced in the process of thermal decomposition (calcination) of naturally occurring calcium carbonates (e.g. limestone, chalk, shells) or naturally occurring calcium and magnesium carbonate (e.g. dolomitic limestone, dolomite)
- **building lime** – a group of products, including only two branches: non-hydraulic lime and lime with hydraulic properties, used in workmanship or building materials, construction and civil engineering
- **non-hydraulic lime** – lime, which binds and hardens in the presence of carbon dioxide from the air
- **hydraulic lime** – building lime consisting mainly of calcium hydroxide, calcium silicates and calcium aluminates
- **calcium lime (*CL*)** – non-hydraulic lime containing mainly calcium oxide and/or calcium hydroxide without any hydraulic or pozzolanic additives
- **dolomite lime (*DL*)** – non-hydraulic lime containing mainly calcium oxide and magnesium oxide and/or calcium hydroxide and magnesium hydroxide without any hydraulic or pozzolanic additives
- **quicklime (*Q*)** – non-hydraulic lime, mainly in the form of oxides, which reacts exothermically with water; is available in various forms - from lumps to powder
- **slaked lime (*S, S PL, S ML*)** – non-hydraulic lime, mainly in the form of hydroxides, obtained as a result of controlled slaking of quicklime; is available in the form of dry-slaked lime powder (***S***), lime putty (***S PL***) or colloidal suspension, possibly whitewash (***S ML***)

## 2.2.Introduction

According to standard PN-EN 459-1:2012 building lime is a group of lime binders including non-hydraulic lime and hydraulic lime (Fig. 1). Lime binders, in industrial practice, are obtained by burning pure limestone or dolomite limestone at a temperature up to 800-1200°C. During this process, an endothermic reaction of the decomposition of calcium carbonate ($CaCO_3$) to calcium oxide (CaO, quicklime) and carbon dioxide ($CO_2$) occurs as following:

$$CaCO_3 \rightarrow CaO + CO_2, \Delta H < 0$$

The parameters of the burning process and the type of used raw materials are the key factors influencing the properties of the resulting product, thus the quicklime. Too high temperature will result in obtaining so-called still-burnt lime, which is compact, difficult to extinguish and causes the lack of stability of the mortar volume. Lime produced at a lower temperature is more active, but too low temperature can lead to a situation where some calcium carbonate will not decompose into calcium oxide and carbon dioxide. As a result, the obtained lime is unburned, contains non-decomposed calcium carbonate and usually is slaking quickly.

The reactivity of quicklime depends on the purity of the raw material (type of rock, amount and distribution of contaminations) and on the burning temperature. The increase in temperature causes an increase in lime density, an increase in the size of CaO grains, a decrease in lime specific surface area and the porosity. Depending on the burning temperature of the raw material following lime can is obtained:

- Light-burnt lime – T ≈ 1000°C, white, very high specific surface area value and high reactivity, CaO crystals with dimensions of about 1 ÷ 2 μm,
- Medium-burnt lime – T ≈ 1150°C, beige or yellow color, CaO crystals with dimensions of about 3 ÷ 6 μm,
- High-burnt lime – T ≈1 250°C, dark yellow or light brown color, low reactivity,
- Still-burnt lime – T ≈ 1300°C, CaO crystals > 10 μm.

Due to reactivity expressed as a temperature increase per unit of time, during slaking of quicklime, there can be obtained:

- very reactive quicklime – slaking quickly (≤ 6 min); too little water can cause overheating burning, manifested by browning of the lime,
- medium reactive quicklime – slaking at a moderate rate (6 ÷ 9 min),
- low reactive quicklime - slaking slowly (≥ 9 min), contaminated or containing more MgO.

Lightly ground quicklime ***(Q)*** is used for the production of lime-sand products, while medium and roughly ground lime is used for the production of cellular concrete, as well as in road construction for stabilization and drying of the soil.

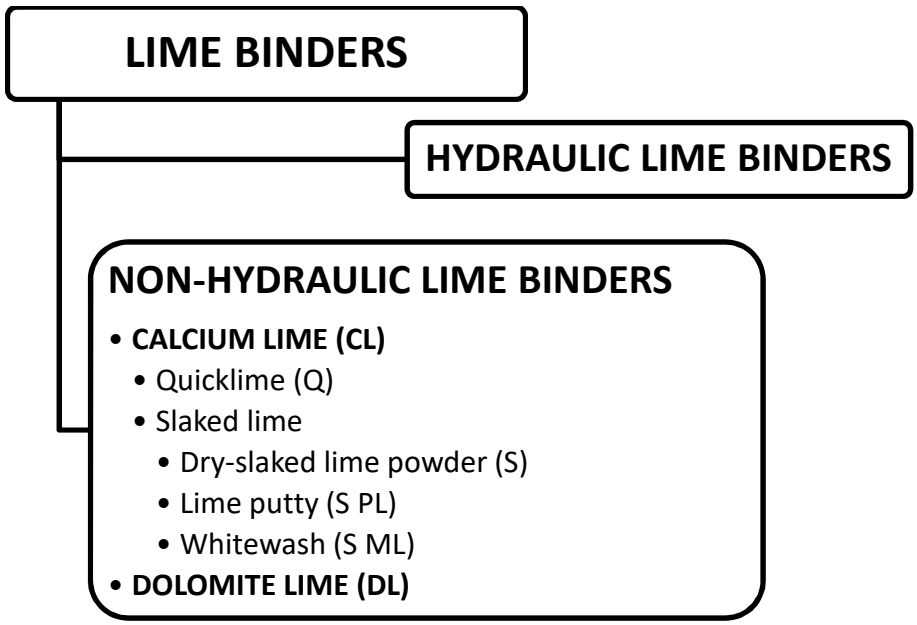


Fig. 1. Types of lime binders according to standard PN-EN 459-1:2012

The process of quicklime slaking involves the reaction of calcium oxide (CaO) with $H_2O$, resulting in hydrated slaked lime (***S***):

$$CaO + H_2O \rightarrow Ca(OH)_2 + 1160\frac{kJ}{kg}CaO$$

This exothermic reaction is accompanied by an increase in the system temperature up to 100°C and in consequence some of the water evaporates. The amount of water used in the process of slaking of quicklime determines the form of slaked lime obtained, i.e.:

- dry-slaked powder (*S*) – calcium hydroxide obtained using possible smallest (close to a stoichiometric) amount of water,
- lime putty (*S PL*) – the mix of calcium hydroxide and saturated solution of calcium hydroxide in water produced as a result of lime slaking with excess of water,
- whitewash (*S ML*) – colloidal suspension of calcium hydroxide in water formed as a result of lime slaking with huge excess of water.

Slaked lime is used primarily for the preparation of masonry and plastering mortars, lime paints and concrete as well as in road construction for soil stabilization and asphalt mix production.

The characteristic properties of lime are as following:

- white colour,
- very high grading – Improves workability and plasticity of cement mortars and concretes,
- exothermic reaction with water – used for dehumidification of e.g. soli and for works in winter,
- strong alkalinity – allows neutralizing other materials, has bactericidal properties, prevents the development of microorganisms,
- ability to absorb significant amounts of water – prevents too quick water being drawn through the ground,
- cracking resistance – reduces mortar susceptibility to cracking,
- ability to chemical reactions with pozzolanic and hydraulic materials – used for the production of building binders, concrete or lime-fly ash mixtures for road foundations,
- low mechanical strength – mortar strength of 1 ÷ 2 MPa
- ability to form strong calcium silicates with sand - used for the production of silicate elements (e.g. bricks, blocks) and autoclaved cellular concretes.

Selected requirements for non-hydraulic calcium lime (CL) lime according to PN-EN 459-1:2012 and their classification on the basis of content of CaO and MgO or $Ca(OH)_2$ and $Mg(OH)_2$ [%, by mass] are given in table 1. Table 2 contains a list of tests used to evaluate the performance of non-hydraulic lime for the building purposes included in the standard PN-EN 459-1:2012.

Table1. Selected requirements for non-hydraulic lime according to PN-EN 459-1:2012

| **Descriptive marking** | **Symbol** | **Content of mass, %** | |
|---|---|---|---|
| | | **CaO + MgO / $Ca(OH)_2$ + $Mg(OH)_2$** | **MgO / $Mg(OH)_2$** |
| Calcium lime 90 | *CL 90* | ≥ 90 | ≤ 5 |
| Calcium lime 80 | *CL 80* | ≥ 80 | ≤ 5 |
| Calcium lime 70 | *CL 70* | ≥ 70 | ≤ 5 |

Table 2. Tests of the performance of building non-hydraulic according to the standard PN-EN 459-1:2012

| Test | Quicklime | Slaked lime | | |
|---|---|---|---|---|
| | | *S* | *S PL* | *S ML* |
| Content of CaO + MgO | + | + | + | + |
| Content of $CO_2$ | + | + | + | + |
| Content of MgO | + | + | + | + |
| Content of $SO_3$ | + | + | + | + |
| Gran size | + | + | - | - |
| Grain size distribution | + | - | - | - |
| Stability of volume | + | + | + | + |
| Penetration (test of the lime mortar) | - | + | - | - |
| Water demand (test of the lime mortar) | - | + | - | - |
| Air content (test of the lime mortar) | - | + | + | + |
| Content of reactive calcium | + | + | + | + |
| Content of free water | - | + | - | - |
| Reactivity | + | - | - | - |
| Bulk density | + | + | - | - |
| Efficiency | + | - | - | - |
| Degree of whiteness | + | + | + | + |
| + tested, - not tested | | | | |

# 3. Practical tasks:

## 3.1. Slaked lime grade of grinding by sieve method according to standard PN-EN 196-6:2016

### 3.1.1. Materials and equipment

- non-hydraulic slaked lime specimen,
- 0.2 mm sieve with bottom,
- 0.09 mm sieve with bottom,
- laboratory scale.

### 3.1.2. Task completion

The test consists in sieving the lime specimen through two sieves with square mesh sizes of 0.09 mm and 0.2 mm and determining the sieve residue – the mass of grains remaining on the subsequent sieves. To perform the determination, weigh a 10 g specimen of slaked lime with an

accuracy of 0.01 g. The weighed material is transferred to a sieve with a mesh side of 0.09 and moved with a horizontal sieve in a circular motion until the particles stop passing through. The residue on the sieve is weighed and then sieved through a 0.2 mm sieve. Residues on subsequent sieves refer to the mass of the analytical specimen of lime and express the result in percent with an accuracy of 0.1%. The test is carried out twice and the average percentage residue on both sieves, with an accuracy of 0,1%, is taken as the result of the determination.

### 3.1.3. Results

The residue of lime which pass through the control sieve with a mesh size of 0.09 and 0.2 mm should comply with the requirements indicated in the standard PN-EN 459-1:2010 (table 3).

Table 3. Physical requirements for slaked lime according to standard PN-EN 459-1:2010 – the sieve residue

| **Type of lime** | **Sieve residue content by mass [%]** | |
|---|---|---|
| | **Sieve 0.09 mm** | **Sieve 0.2 mm** |
| CL 90 | ≤ 9,0 | ≤ 4,0 |
| CL 80 | | |
| CL 70 | | |

### 3.1.4. Elaboration of results

The results should be presented in the form of a table (table 4):

Table 4. Example of the table presenting the results obtained during the test

| Type of the lime:<br>Mass of the specimen No 1:<br>Mass of the specimen No 2: | | | | | |
|---|---|---|---|---|---|
| Sieve size/residue | Measurement No 1 | | Measurement No 2 | | Average value [%] |
| | [g] | [%] | [g] | [%] | |
| 0.09 | | | | | |
| 0.2 | | | | | |
| Conclusion: The obtained results meet/do not meet the requirements in standard PN-EN 459-1:2012 | | | | | |

## 3.2. Reactivity of quicklime using the beaker method (simplified method)

### 3.2.1. Materials and equipment

- mon-hydraulic quicklime specimen,
- Distilled water,

- scale,
- set of two aluminum beakers with a capacity of 350 ml and 450 ml, inserted one into the other, equipped with a lid equipped with a thermometer.

### 3.2.2. Task completion

The test of lime reactivity during slaking is carried out using the simplified beaker method, consisting in measuring the time in which the mixture of quicklime and water reaches the maximum of the temperature. Measure 40 ml of distilled water into a beaker and weigh 20 ± 0.1 g of quicklime. Pour the lime specimen into the beaker while starting the stopwatch. Then cover the beaker, making sure that the thermometer is immersed in the mixture, then lightly shake and set aside. Read and record the temperature at intervals indicated by the teacher. Measure until the maximum temperature is maintained for three consecutive measurements. The test result is expressed as the time t [min] necessary to reach the maximum temperature T [°C].

### 3.2.3. Results

The temperature values (measured in °C) are presented graphically in a function of time (in minutes) – see Fig. 2.

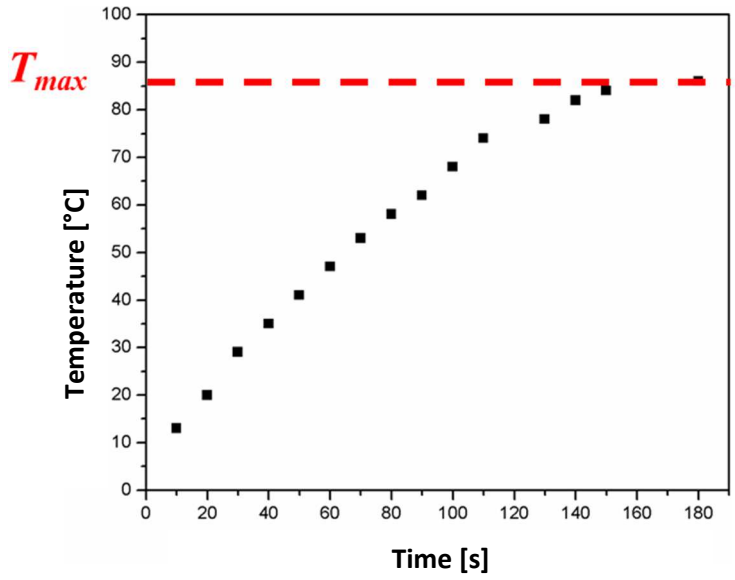


Fig.2. An example graph presenting dependence of temperature on the time of extinguishing of quicklime

Due to the technological requirements for the production of autoclaved aerated concrete, the tested quicklime should meet the following reactivity requirements:

- slaking time from the range of 10 to 30 minutes,
- slaking temperature over 60°C.

### 1.1.1. Elaboration of results

The results should be presented in the form of a table (table 5):

Table 5. Example of the table presenting the results obtained during the test

| Type of lime:<br>Mass of the specimen:<br>Mass of distilled water: | | | |
|---|---|---|---|
| Reactivity | Measurement No 1 | Measurement No 2 | Average value |
| Time [min] | | | |
| Temperature [°C] | | | |
| Conclusion: The obtained results meet/do not meet the technological requirements formulated for the production of autoclaved aerated concrete. | | | |

# 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)