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Technical Evaluation of Construction Mortars with Various Lime Quantity Additions

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Abstract. Construction mortars are materials for common use. The broad range of their usage results from their technical parameters and consequently from possibilities of various material and technological solutions. They can be used in various solutions both in existing objects as well as new-built ones. The history of using mortars reaches very old times. Lime as a binder was applied already about 3000 BC for building pyramids, decoration and finishing of building walls. Over time lime was added with pozzolan thanks to which the mixture gained better technical parameters. Currently, for design of mortar with necessary physical and strength properties it is needed proper component selection, their dosing and mixing. Essential role is played here by correct proportions and quality of components. Too low or high contents of particular components can significantly influence their technical properties. This article concerns the evaluation of influence for various quantities of hydrated lime (10, 20 and 30% in relation to cement amount) added to mortars on their basic technical parameters and microstructure defined with mercury porosimetry method. Microscopic tests were performed according to the Polish standards. They include evaluation of permeability, compression and flexural strength. During the microstructure tests the cumulative curve of pore volume in relation to their diameters was obtained. On its base the percentage contents of mezzo- and macropores was defined depending on type of mortar sample types. It was found that lime addition essentially influences technical parameters obtained.

1. Introduction

Lime is a building component known and used by humans for thousands years. It is a binding substance of high technical parameters. With the development of industry, it was partially replaced by cement and its application has been reduced. Currently there is a trend to popularize lime mostly because of its pro-ecological advantages. It is a material which excellently fits into renewal of historical monuments and present day objects using mortar mixtures, construction mortars, and binding masses.

Construction mortars belong to a group of materials which are chemically active for which there are defined two corrosion types: internal and external (figure 1). The external corrosion includes all cases when the mortar is threatened with unfavourable environmental factors (gaseous CO₂, rain, changing temperatures, air humidity, soluble mineral salts originating from surrounding elements) [1,2]. The internal factors include mortar components and their interactions. These interactions contribute to destruction of the material structure. This process is distributed over a time period.





Figure 1. Exemplary effect of mortar corrosion

In this work the evaluation of lime addition influence of 10, 20, and 30% into mortars, on their basic technical parameters was performed with the mercury porosimetry method. The tests resulted in a cumulative curve which enabled to define percentage share of meso- and macropores in mortar samples taken.

Currently cement-lime mortars are growing both in popularity and significance. Hydrated lime ensures good plasticity and workability of mixtures, better base adhesion, and better resistance to scratches in hardened mortars, while cement enhances their compressive strength. It is estimated that introduction of lime into cement mortars can even double their adhesion comparing to mortars with plasticizers. Additionally, increased lime quantity leads to extended mortar setting time which keeps moisture longer so volume changes, contraction, scratches and pores are minimized [1,3].

2. Materials and tests

The following construction mortar were selected for the tests:

- CEM I 42.5 cement mortar based on portland cement (model mortar),
- CEM I cement mortar with 10% of CL90 hydrated lime addition,
- CEM I cement mortar with 20% of CL90 hydrated lime addition,
- CEM I cement mortar with 30% of CL90 hydrated lime addition.

The mortar content was according to table 1. The number of samples was 6 for each type of tests.

Table 1. Composition of tested mortars

Mortar	Mortar content of 1 m ³			
	Cement CEM I 42.5N [kg]	Lime [kg]	Sand [dm ³]	Water [dm ³]
CEM I	378	-	1.05	0.253
CEM I + 10% of lime	378	37.7	1.05	0.273
CEM I + 20% of lime	378	75.3	1.05	0.284
CEM I + 30% of lime	378	113.0	1.05	0.232

Concerning the practical use of the selected mortars in selection of quantity proportions for components recommendation from table 2 were taken into account. The consistence was assumed as 6-8 according to the Abrams cone.

Table 2. Recommended types and class of cement-lime mortars depending on their designation [3]

Designation		Type symbol	Class
Foundation and external walls below the ground level	Construction	CL	M10; M15
	non-construction	CL	M10; M15
External walls above the ground level	Construction	CL	from M5 to M15
	non-construction	CL	M5; M10

The assumed mortars were formed in standard beams sized 40x40x160mm. After 28 days of conditioning the mortar samples were dried to solid mass in temperature of $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$. Such prepared material was measured as for macroscopic features according to the binding Polish standards about: water absorption by soaking method [4], compressive and flexure strength [5,6]. Additionally, microstructure test was performed by mercury porosimetry method.

The water absorption test was performed by gradual emersion of samples in water ($\frac{1}{2}$ of sample height – 2h, $\frac{3}{4}$ of sample height – 2h, total emersion). The results as arithmetic average from six samples are presented in table 3. In order to define the flexural strength, mortar samples were uniform loaded with a force concentrated in their centre until they broke. The flexural strength was calculated based on the breaking force value and sample measurements. The results were showed as arithmetic average.

The compression strength tests were performed on 6 halves of beams which were previously tested in the breaking tests. The test defines the maximum tension which the mortar sample is able to transfer in relation to pressing plate surface (1600 mm). The result is an arithmetic average of 6 samples – table 3. In order to define the properties associated with the porosity of mortars selected to tests the mercury porosimetry method was used. The porosimetry tests were made by a Micrometric company porosimeter AUTOPORE IV model. The type of porosimeter used let run the tests of porosity structure within diameters from $0.003 \cdot 10^{-6}$ m to $360 \cdot 10^{-6}$ m. The tests were made on porosimeter Auto Pore IV series 9500 equipped with two ports: low and high pressure with maximum value of 33000 psia (228MPa), which let measure in the range of meso - and macropores (from $2 \cdot 10^{-9}$ m to $360 \cdot 10^{-6}$ m). Before the test the calibration and blank test were performed – defining volume, compressibility and thermal effect of the penemometer used. Basing on control measurements the equilibrium time was set which was 30s. As a result of measurements there were set: porosity, specific material area (total internal area of pores in a unit of material mass), substitute pore diameter, apparent density, and specific density.

Based on measurement of mercury volume penetrating into pores in particular equilibrium pressure, the distribution of pore volume in function of their radius was set using the Washburn rule connecting pore size with pressure:

$$d = - \frac{4 \cdot \gamma \cdot \cos\theta}{p} \quad (1)$$

where:

γ – surface tension of mercury at σ (293K) = $42.8 \cdot 102 \text{ N} \cdot \text{m}^{-1}$

θ – mercury moistening angle – 130° (commonly accepted value in laboratory tests)

P – pressure in bars.

For setting of the correction for mercury compressibility a marking of dilatometers was performed by analysis without a sample (blank test).

Resulting from the measurements of the samples prepared, the following structure parameters were defined: total pore volume, sample volume and its skeleton density, pore volume density in function of their diameter as an integral and differential relation.

The pore volume share was calculated from the following formula:

$$U_{\text{MEZO}} = \frac{\sum_{i=2\text{nm}}^{50\text{nm}} IV_{\text{MEZO}}}{TIV} \cdot P \quad (2)$$

$$U_{\text{MAKRO}} = \frac{\sum_{i=50\text{nm}} IV_{\text{MAKRO}}}{TIV} \cdot P \quad (3)$$

where: IV_{MAKRO} - % share of macropores > 50nm, IV_{MEZO} - % share of mesopores 2-50nm, P – total porosity.

3. Results and discussions

Based on macroscopic tests there were obtained average values of water absorption, flexural and compression strength (table 3). The samples based on portland cement CEM I were characterized with significantly lower water absorption in relation to samples with hydrated lime. The differences were estimated at level of 100 and even 150% proportionally according to lime share. In case of compression and flexural strength according to expectation the lime causes weaker results. The compressing strength in samples with 30% lime additions is lower by over 3MPa in relation to mode I samples. With increasing share of lime the mortar becomes more elastic which lowers the risk of cracks and scratches. The results of flexural tests show the similar trend.

Table 3. Selected technical parameters of construction mortar samples

Laboratory marking	Cement mortar CEM I 42.5	CEM I cement mortar with addition of CL 90 hydrated lime		
		10%	20%	30%
Weight water absorption (%)	5.1	11.8	13.9	15.6
Flexural strength (MPa)	6.3	5.1	4.9	4.6
Compressive strength (MPa)	14.8	13.2	13.5	11.8

As a result of mercury porosimetry the following basic microstructure parameters were obtained (table 4):

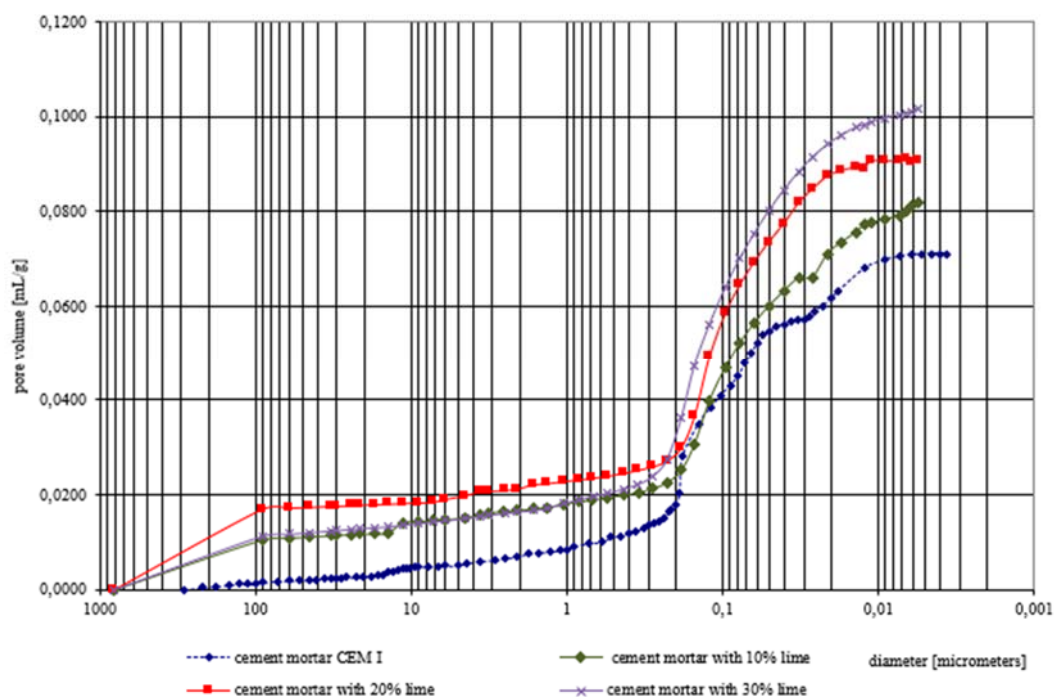
- volume density as a relation of porosity mass to the total volume of porosity sample,
- real density of the skeleton material defined as a relation of porous dry material mass to the skeleton volume,
- porosity – a relation of pore volume contained in a given volume of a porous body to its total volume,
- sinuosity as a geometric non-unit value defining the average length of a liquid particle path moving from one point of a porous medium to another, related to the distance between these points along the straight line).

The obtained graph (figure 2) is a cumulative curve of pore volume depending on their diameter obtained with increasing pressure. On the logarithmic x axis, there are pore diameters [μm]. On the y axis – the volume of pore space occupied by mercury injected into a sample under pressure. The y axis is scaled in millilitres of mercury volume for 1g of a sample [ml/g]. Based on the integral curve of pore size distribution the share of meso- and macropores in the material tested samples was defined (table 4).

Table 4. Basic microstructure parameters of the tested mortar samples

Microstructure parameters	Cement Mortar	Cement mortar with CL 90 hydrated lime		
		10%	20%	30%
Mercury intrusion, mL/g	0.109	0.078	0.097	0.102
Volume density, g/mL	1.97	2.06	1.98	1.94
Specific weight, g/MI	2.50	2.46	2.43	2.41
Porosity %	23.96	19.86	17.91	15.78
Sinuosity	2.32	3.38	3.36	3.41
Mesopores 2-50nm, %	22.14	18.19	16.54	14.80
Macropores > 50nm, %	1.82	1.67	1.37	0.98

During the tests the significant differences in the microstructure of the mortars were found. The model cement mortar is characterized with the highest specific weight; the introducing of lime proportionally lowers this parameter. The porosity of the cement mortar is close to 24% and includes mostly mesopores. The share of macropores is at the level of 1.82%, and it's the highest in comparison to the other mortars. In mortars with lime addition the porosity decreases proportionally from 19.86 to 15.78%. It can be noticed here the lowering of macropores share along the increasing lime addition from 0.98 to 1.67%. The mesopores decide about the sorption parameters of a material. Macropores play a role in humidity transport to mesopores, they can lead to appearance of cracks and scratches. Additionally, the increasing macropore number influences the permeation of aggressive water solutions into the wall interior. This can result in occurrence of all kinds of unnecessary efflorescence.

**Figure 2.** Integral curve of pore volume distribution in mortar samples

4. Conclusions

In this work there is an analysis of changes in selected technical parameters and microstructure of mortars added with various amounts of hydrated lime. The results obtained indicate univocally the volume changes in macro- and mesopores depending on assumed mortar type.

During the wall exploitation the mortar is affected by unfavourable environment influence: changing temperature and air humidity, dynamics of wind and rain. These factors negatively influence its aesthetics and durability. The properly selected mortar and wall element should not only be characterized with high strength, but also guarantee the tightness – limiting the possibility for moisture migration to the wall interior. Additionally, it should be a barrier for rain water and enable its easy releasing outside when it already appears. Thus it is very important its adhesion to the base, permeability and microstructure stability [7,8]. In mortars with lime additions the permeability is high which enables water drainage from moistened walls. These mortars proportionally to the increased lime addition show high water retention which improves better abutting to the wall element [9]. Hydrated lime limits the occurrence of scratches and cracks and acts with on principle of “self-medication”. The mortar becomes more elastic which in consequence limits linear changes occurring in the wall [10].

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