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RESISTANCE OF MORTARS WITH GYPSUM, LIME AND COMPOSITE BINDERS AGAINST MOLDS

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Abstract. Resistance of three mortars (the lime mortar, the gypsum mortar and the mortar with the composite binder) against molds was evaluated. Mortars were also compared according to their pH, bulk density, strength and porosity. Experiments showed that the lime mortar has the best resistance against molds and the lowest bending and compressive strength. The mortar with the composite binder has better mold resistance and higher bending and compressive strength than the gypsum mortar.

Keywords: Calcium sulfate dihydrate, gypsum, mold resistance, mortars, plasters.

1. Introduction

Gypsum is widely used material in building industry especially for production of gypsum plaster, plasterboard (drywall), gypsum blocks [1] and some composite materials. Gypsum plaster often contains filler, which can improve thermal insulation properties, reduce binder consumption, reduce volume changes during exposure to high temperatures [2] etc. In terms of composition, gypsum plaster with filler is actually gypsum mortar (it contains calcium sulfate hemihydrate based binder, fine aggregate and water). Production of gypsum based products is more environmentally friendly [3] and faster than production of cement based products. However, use of gypsum products is significantly limited by their low moisture resistance. According to recent research [4], moisture resistance can be improved by adding lime and silica fume to gypsum binder where lime acts as an alkaline activator of the pozzolan reaction. Mortar with such binder is being developed and researched [5], but some of its properties are still unknown, for example mold resistance which is important but often neglected property. Molds belong to microorganisms, that commonly appear on inner and outer surfaces of building structures and can cause sick building syndrome (people in a building feel ill from no apparent reason) and threaten human health [6]. Molds also damage building materials by biodegradation (synergic process of chemical and physical biodegradation) [7]. In general, gypsum based materials have worse mold resistance than cement based materials [8], [9] which corresponds with different pH of these materials. However, e.g. water content in materials and additives also play an important role [8]. That's why this paper is focused on the possibility of improving the mold resistance of gypsum mortat by adding lime and silica fume to the gypsum binder. Also pH, bulk density, strength and porosity of the lime mortar, the gypsum mortar and the mortar with the composite binder (gypsum, lime and silica fume) is tested and compared.

2. Materials

The mortars were made of grey gypsum binder (Gypstrend s.r.o.), white hydrated lime (Vápenka Čertovy schody a.s.), silica fume (Stachesil S, Stachema), standardized sand (according to the ČSN EN 196-1 [10] standard) and water. Silica fume was used as a pozzolan additive and hydrated lime was added as an activator of the pozzolanic reaction. The compositions of the mortars are in 1.

3. Experimental Methods

Sample preparation and testing. Squared samples of 30 × 30 × 3 mm size were prepared for mold growth testing. Prisms of 40 × 40 × 160 mm size were prepared for physical properties testing according to the ČSN EN 13454-2+A1 [11]. Dry components of binders were mixed, poured into water and placed in standardized automatic mixer. Sand was added after 30 s of mixing. Mixtures were put in moulds on 2 - 24 hours and then they were put out of moulds and stored in laboratory conditions for at least 28 days. After that, experiment was divided into four modifications (as shown in Table 2) according to the type of sterilization and location of samples.

Mediums used in modification A, B, and C were following (D was without medium):

- (CZ) Czapek-dox (commercial medium produced by Oxoid)
- (MIN) mineral medium (follow composition per l: 2 g $NaNO_3$; 0.7g KH_2PO_4; 0.3g K_2HPO_4; 0.5g $MgSO_4 \cdot {}_7H_2O$; 0.01g $FeSO_4 \cdot {}_7H_2O$) according to the ČSN EN ISO 846 [12].

Each sample was placed in the center of petri dish with medium. All squared samples and mediums were inoculated by spreading of physiological solution with four commonly occurring molds - *Cladosporium cladosporioides, Asperigillus versicolor, Stachybotrys*

Sample	Calcined gypsum [wt. %]	Lime [wt. %]	Silica Fume [wt. %]	Sand [wt. %]	Water/binder ratio [-]
GM	33	-	-	67	1
LM	-	3.3	-	67	1
GLSM	27	3.2	2.8	67	0.82

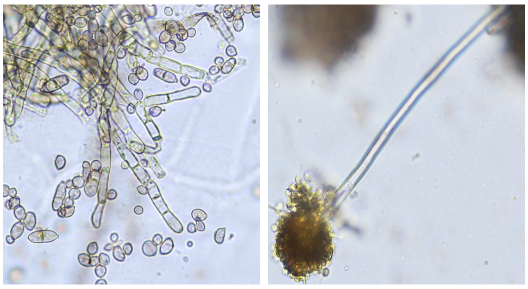
Table 1. Composition of mortars

	Sample sterilization	Storage of inoculated samples
A	-	on mediums in Petri dishes in biological thermostat
B	alcohol and UV radiation	on mediums in Petri dishes in biological thermostat
C	autoclaving	on mediums in Petri dishes in biological thermostat
D	-	100% RH in desiccator

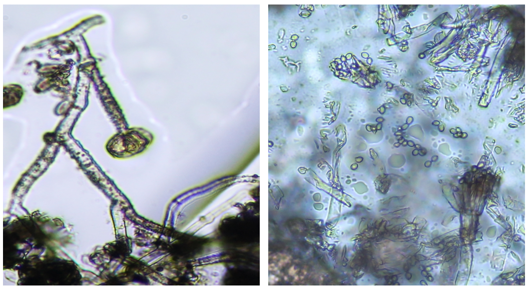
Table 2. Modifications of Experiment

chartum and Penicilium purpurogenum which are obtained from Czech collection of microorganism (CCM).

The microscope pictures of the molds are below (1a , 1b - all pictures are in the same scale). The incubation was at 26 °C for three months. Rate of mold growth was monitored for 4 - 12 weeks every week as a cover of sample and halo effect around the sample. After the finishing of experiment the samples were evaluated by microscopy.



(a) Left - Cladosporium cladosporioides, right - Asperigillus versicolor.



(b) Left - Stachybotrys chartum, right - Penicilium purpurogenum.

Figure 1. Microscope pictures

Samples were stored for 28 days in laboratory conditions. Their pH was determined by pH paper from dispersion of crushed samples in distilled water. Bulk density ρ_v [kg/m^3] was determined by gravimetric method on dried prismatic samples. Bending strength f_f [MPa] and compressive strength f_c [MPa] were determined using press FP 100 (VEB Industriewerk Ravenstein) in accordance with the ČSN EN 13279-2 [13] on dried prismatic samples. Porosity and pore size distribution were determined using mercury intrusion porosimetry device Pascal 140 + 440 (Thermo Scientific) on dried pieces of prismatic samples.

4. Results

Physical and chemical properties. Values of pH are summarized in table 3. As expected, the gypsum mortar has the lowest pH. Bulk densities of all mortars are similar, as can be seen in table 3. Bending and compressive strength of mortars are in 2. The mortar with the composite binder (GLSM) has almost three times higher compressive strength than the lime mortar (LM) and more than one and half times higher compressive strength than the gypsum mortar (GM).

Sample	pH	Bulk density [kg/m^3]	Porosity [-]
GM	6	1 458	42.5
LM	10	1 642	32.6
GLSM	11	1 581	38.5

Table 3. Physical and chemical properties of mortars.

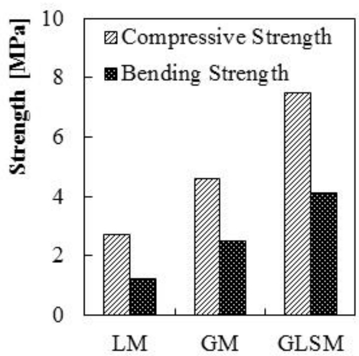


Figure 2. Bending and compressive strength.

Total porosity of all mortars is similar (see table 3). The gypsum mortar has primarily pores of size about 1 μm 3. The mortar with the composite binder has these pores partially filled by CSH-phases formed during the pozzolanic reaction [5]. Size of pores in the lime mortar is between 10^{-8} m and 10^{-4} m. Therefore, all three mortars have mainly capillary pores

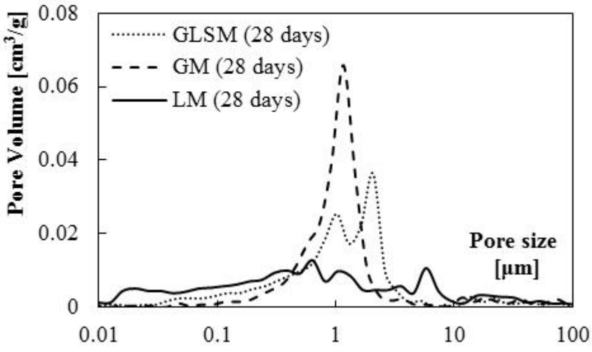


Figure 3. Pore size distribution.

(10^{-9} - 10^{-3} m). In these capillary pores, water movement is induced by surface tension (capillary forces) and that is why rising dump may occur in these materials. Moisture significantly support mold growth and therefore, moisture transport properties of materials are important. It can be expected, that moisture transport properties of the three mortars differs due to the different pore size distribution.

Resistance against molds. Mortars resistance against molds was evaluated using the five point scale, where: 0 - no molds, 1 - mold growth is visible under microscope, 2 - molds cover less than 25 % of sample surface, 3 - molds cover 25 - 50 % of sample surface, 4 - molds cover more than 50 % of sample surface, 5 - molds completely cover sample surface. Mean results are in table 4. Mold growth on different samples made of same material and same modification was similar.

Results show that molds grow more and faster on samples with lower pH (about 6), respectively on samples without lime, which corresponds to literature [9]. Results also show higher resistance to mold growth of unsterilized samples A. It could be caused by the fact that some microorganisms that decelerate mold growth were destroyed by sterilization. On the lime mortar (LM), mold growth did not appear during the experiment and so called halo effect (see 5) occurred around samples A and B. It means that medium near sample was influenced by the sample. Leaches (probably $Ca(OH)_2$ leaches) formed around the sample and molds did not grow in this inhibition zone (see 5). The lime mortar (LM) can be classified as biocidal (for about four weeks) due to this phenomenon. Halo effect did not occur around autoclaved samples C. It was probably caused by the release of free Ca_2^+ ions during autoclaving. Halo effect also appeared around the mortar with the composite binder (GLSM) probably due to its $Ca(OH)_2$ contain. This mortar sustains the biocidal properties for four days. Microorganisms probably created the appropriate growth environment for molds during this time. Mold growth occurred after one week on samples on the Czapek-Dox medium. Molds did not grow on samples on the mineral medium. Fast mold growth and no halo effect were observed on the gypsum mortar (GM) in accordance with literature [14]. Molds were observed few weeks after inoculation even on surfaces of the samples on mineral medium. This mortar has therefore worse resistance against molds than the mortar with the composite binder. However, mold growth on all tested mortars is caused by the presence of medium in the pores of the samples. It is proved by the modification D. All samples in modification D were monitored for 12 weeks and mold growth was not observed. After 12 weeks, some molds were observed under microscope. These molds were probably spread on sample surface during inoculation at the beginning of experiment and they have not grown since that. It means that tested mortars do not have enough essential nutrients for mold growth. Results show that relatively low content of lime and silica fume in gypsum binder significantly improved resistance of mortar against molds.

5. Conclusion

Resistance against molds, pH, bulk density, strength and porosity of the lime mortar, the gypsum mortar and the mortar with the composite binder (gypsum, lime and silica fume) were investigated. Experimental results showed that:

- the mortar with the composite binder has almost three times higher bending and compressive strength than the lime mortar and about one and half times higher bending and compressive strength than the gypsum mortar (GM);
- the gypsum mortar has the lowest pH value;
- pore size distribution of the mortars differs while their total porosity and bulk density are similar,
- the tested mortars do not have enough essential nutrients for mold growth (tested time was 12 weeks);
- molds grow on the gypsum mortar and on the mortar with the composite binder if nutrients are added,
- molds do not grow up on the lime mortar (during 6 weeks); the lime mortar has the best resistance against molds and the gypsum mortar has the worst resistance against molds,
- inhibition zone occurred around the lime mortar and the mortar with the composite binder and these mortars can be classified as biocidal (for 4 weeks - the lime mortar, resp. 4 days - the mortar with the composite binder).

The mortar with the composite binder has better mold resistance and higher bending and compressive strength than the gypsum mortar. The mortar with the composite binder is therefore more suitable for use in practice, e.g. as a plaster in building structures. Future research might be focused on mold resistance improving for example by adding nanoparticles [8].

Acknowledgements

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Sample	Modification	Time [week] (medium CZ)						Time [week] (medium MIN)					
		1	2	3	4	5	6	1	2	3	4	5	6
GM	A	2	2	2	2	-	-	0	0	0	0	-	-
	B	3	4	4	4	4	4	0	0	0	2	2	2
	C	4	4	4	4	4	-	0	0	0	0	0.5	-
	D	-	-	-	-	-	-	-	-	-	-	-	-
LM	A	0	0	0	0	-	-	0	0	0	0	-	-
	B	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	-	0	0	0	0	0	-
	D	-	-	-	-	-	-	-	-	-	-	-	-
GLSM	A	2	2	2	2	-	-	0	0	0	0	-	-
	B	0	2	3	3	3	3	0	0	0	0	0	0
	C	2	2	2	2	2	-	0	0	0	0	1	-
	D	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 4. Mold growth

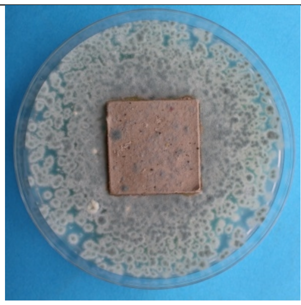
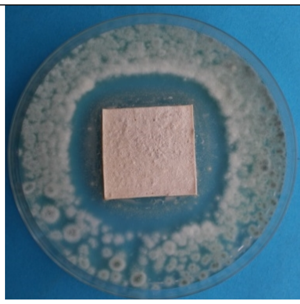
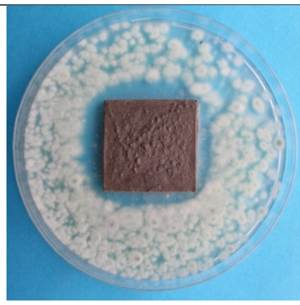
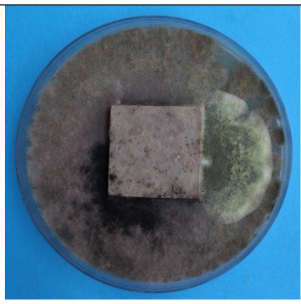
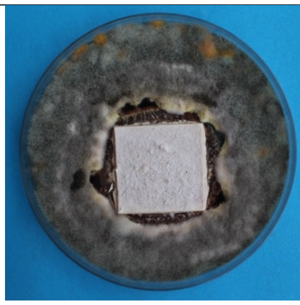
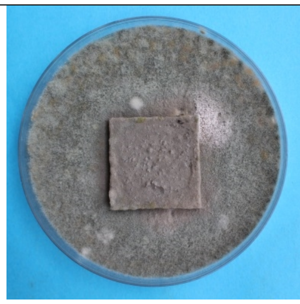
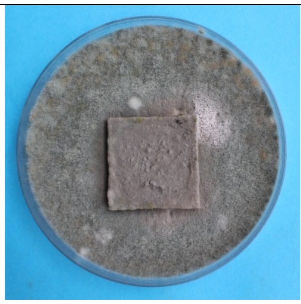
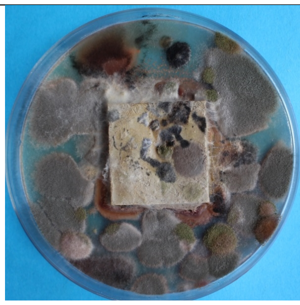
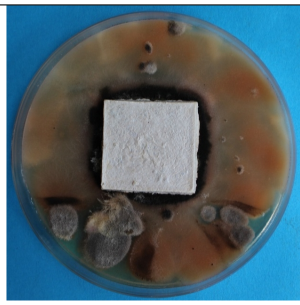
	GM	LM	GLSM
Modification A (4 days)			
Modification B (4 weeks)			
Modification C (4 weeks)			

TABLE 5. Inoculated Samples, Czapek-Dox Medium.

Laboratory, Department of Building Structures, Faculty of Civil Engineering, Czech Technical University, Prague, namely with Mgr. Pavla Ryparová, Ph.D. and Ivana Loušová.

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