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MAGNESIUM OXYCHLORIDE CEMENT-BASED COMPOSITE WITH FOAM GLASS USED AS LIGHTWEIGHT ADMIXTURE

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In this paper, foam glass was used as an aggregate in magnesium oxychloride cement (MOC)-based mixtures. Magnesium oxychloride cement is known as a non-hydraulic, high-strength, and fire-resistant binder that can bond large amounts of miscellaneous fillers. In comparison with Portland cement, MOC has a lower environmental impact over its whole life cycle. The purpose of this paper is to modify thermal and hygric properties of MOC-based composites using lightweight mineral admixture, namely foam glass, and hydrophobic agents. The raw materials were analyzed by XRF spectroscopy and their basic properties characterized. The MOC composites were by their basic material, mechanical, thermophysical, and moisture properties described. Considerable improvement of thermal parameters of MOC composite modified with the foam glass and obvious action of surface hydrophobic agent as moisture barrier were observed. The resulting thermal-insulating, lightweight MOC composite with suitable mechanical properties can be used in the construction of thermal insulation surfaces and envelopes, ceiling or wall panels, reducing the energy consumption of buildings.

Keywords: Foam glass aggregate, Lightweight MOC composite, Crushed lava aggregate, Thermal properties, Hygric properties.

1 INTRODUCTION

Historically, the global construction materials industry was based on an extremely wide range of building materials convenient for local conditions, exact applications and traditions. Unfortunately, during the last sixty years, the building industry changed to almost a monoculture based on Portland cement (PC), with other materials essentially side-lined. With increasing concern about environmental sustainability, the construction industry must rediscover materials that held largely unique or curiosity value. Contrary to PC manufacture, magnesia-based cement should be classified as a potential CO_2-negative and eco-friendly binder (Walling and Provis 2016).

The MOC is a material with huge binding ability, which can consolidate large quantities of diverse fillers ranging from rocks to dust. It possesses also high compressive and tensile strengths and modulus of elasticity. However, the popularity of MOC, which has been used in the construction industry for more than 150 years, has sharply declined in the past half-century because of its poor water resistance and consequential degradation during service (Bensted 2003). Nevertheless, application of MOC as wallboard seems useful because the market is familiar with gypsum-based products, which are produced on a large scale in many countries. MOC cement is commonly used for the production of magnesia-based sheeting boards which are modified with wood fiber and perlite; additionally the surface is protected from moisture attacks by using glass cloth (Li and Yu 2010). Magnesia cement can be applied in environments that need near-neutral-pH, can be used for rapid repair, especially in cold conditions, for dry internal applications, etc. It represents also a good alternative for conventional binders, e.g. cement and lime, because of its high strength (Chen *et al.* 2017), fire resistance (Fang *et al.* 2018), and applicability with organic aggregates (Wang *et al.* 2018).

Therefore, a new type of magnesium oxychloride cement composite based on light-weight foam glass aggregate modified with hydrophobic agents was developed and tested in this work.

2 EXPERIMENTAL

The experimental research focused on the development of thermal insulated light-weight MOC composite. In order to quantify the effect of the use of foam glass as aggregate and hydrophobic agents, basic structural, mechanical, hygric, and thermal parameters of 28 days cured MOC-based composite samples were assessed.

2.1 Materials and Design

Commercially produced light-burned MgO powder (Styromagnesit Steirische Magnesitindustrie Ltd., Oberdorf, Austria) together with 55% solution of $MgCl_2{\cdot}6H_2O$ (p.a. purity, Lach-Ner, s.r.o., Neratovice, Czech Republic) were used to prepare magnesium oxychloride cement (MOC). The mix preparation was carried out according to the standard EN 14016-2 (2004), where silica sand (Filtrační písky Ltd., Chlum u Doks, Czech Republic) was used as an aggregate in the case of reference MOC, signed as MGR. As a light-weight aggregate, foam glass (RECIFA a.s., Příbram, Czech Republic) was dosed as a volume substitution instead of silica sand, samples signed as MGS. To enhance water resistance of tested MOC, the inner hydrophobization, namely the mixture of Ligastar CA 800 (calcium stearate) and Ligaphob N 90 (sodium oleate) provided by Excel Mix Cz, Ltd., Czech Republic, in a ratio 1:2 was added to batch water, samples named MGSH. The dosage of batch water was adjusted to get similar consistency of all studied composites. The chemical composition and basic material properties of used raw materials are presented in Table 1.

Table 1. Chemical and basic material characteristics of raw materials.

Substance	**Mass %**		
	MgO powder	**Silica sand**	**Foam glass**
MgO	80.50	0.40	2.30
CaO	5.20	-	12.40
Fe_2O_3	3.80	-	0.50
SiO_2	3.80	96.30	65.80
Al_2O_3	6.00	3.10	4.70
Na_2O	-	-	12.00
K_2O	-	-	0.90
SO_3	0.40	-	1.20
BaO	-	-	0.30
Bulk density ($kg{\cdot}m^{-3}$)	3 340	2 650	1 920
Powder density ($kg{\cdot}m^{-3}$)	840	1 660	730
Blain specific surface ($m^2{\cdot}kg^{-1}$)	690	-	-

The chemical composition was determined using X-ray fluorescence (ED-XRF Spektrometer, ARL QUANT´X, Thermo Fisher Scientific, Waltham, USA). The specific density with a helium pycnometer Pycnomatic ATC (Porotec, Hofheim, Germany) was analyzed. The powder density was calculated afterwards from the dry mass of the sample and its volume. The Blaine specific surface was measured in compliance with the standard EN 196-6 (2010).

The composition of investigated MOC-based materials is presented in Table 2. The fresh mixtures were cast in 40 mm × 40 mm × 160 mm prism molds, 70 mm cubic molds, and in circular molds with 100 mm diameter and 20 mm height. Samples covered with polyethylene sheets were cured 24 h. Then they were demolded and placed for the next 27 days at temperature of (21±2) °C and (45±5) % relative humidity.

Table 2. Composition of tested MOC composites (kg·m^{-3}).

	Substance					
Composite	**Light-burned MgO**	**$MgCl_2$**	**Silica sand**	**Foam glass**	**Hydrophobic admixture**	**Water**
MGR	615.60	272.70	1 348.10	-	-	338.60
MGS	615.60	272.70	-	625.00	-	338.60
MGSH	615.60	272.70	-	625.00	18.50	338.60

The particle size of MgO was determined using an Analysette 22 Micro Tec plus (FRITSCH, Idar-Oberstein, Germany). The apparatus operates on a laser diffraction principle. From the three sets of measurements, approximately 45 μm average particle size of MgO powder was detected. The particle size of used aggregates was analyzed by the standard dry sieving method using an automatic sieving machine AS 200 Basic (RETSCH, VERDER s.r.o., Germany). The measured particle size cumulative curves of silica sand and foam glass are presented in Figure 1.

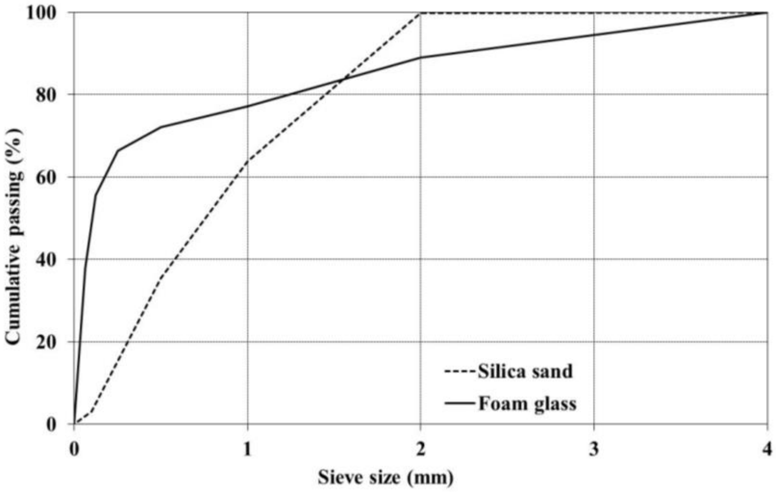

Figure 1. Granulometric curves of used aggregates (sieve size is given in logarithmic scale).

2.2 Testing Methods

The developed composites were characterized by basic material properties, mechanical parameters, and thermal and moisture behavior. Measurements on 28 days air-cured specimens dried in vacuum oven at 60 °C until reaching steady state were performed. First, basic material characteristics, namely specific density ρ_s (kg·m^{-3}) and bulk density ρ_b (kg·m^{-3}) were determined according to EN 1015-10 (1999). Finally, open porosity ψ (%) value was calculated. For these tests, 5 specimens were used. The specific density was obtained by helium pycnometry. The expanded combined uncertainty was 1.4 % and 2.0 % in the case of the bulk density and open porosity tests, respectively.

Mechanical resistance was tested on three prismatic specimens with dimensions of 40 mm × 40 mm × 160 mm. The tests were performed according to the standard EN 1015-11 (1999). The flexural strength f_f (MPa) test was in a three-point bending test arrangement with span 100 mm using mechanical press Heckert PF 100 measured. The compressive strength f_c (MPA) was measured on the fragments of specimens from flexural strength testing with the loading area 40 mm × 40 mm. The relative expanded uncertainty of both strength tests was 1.4 %.

The heat transport and storage parameters as thermal conductivity λ (W·m^{-1}·K^{-1}) and volumetric heat capacity c_v (J·m^{-3}·K^{-1}) were on three cubic samples using apparatus ISOMET 2114 (Applied Precision, Bratislava, Slovakia) measured. The apparatus is working on a heat impulse technique and the expanded combined uncertainty of the thermal properties assessment was 4.3 % and 5.1 %, respectively,

In order to evaluate the durability of MOC composites in respect to water penetration, the free water intake experiment was performed on five cubic specimens. The water absorption coefficient A_w (kg·m^{-2}·s$^{-1/2}$) was then determined according to the EN 1015-18 (2003). The expanded combined uncertainty of the water absorption coefficient test was 2.3 %

The characterization of MOC composites with and without inner hydrophobic treatment was conducted also by the water vapor transmission test. The water vapor diffusion coefficient D (m^2·s^{-1}) and vapor diffusion resistance factor μ (-) were determined using the dry cup method on the basis of the standard EN ISO 12572 (2016) in steady state isothermal conditions at (23±0.5) °C and (50±5) %. The one-dimensional water vapor transport was simulated in the cylindrical samples (diameter of 100 mm and thickness of 20 mm), which were water and vapor-proof insulated on the lateral sides with epoxy resin.

3 RESULTS AND DISCUSSION

The determined basic structural and mechanical properties of hardened MOC composites are summarized in Table 3. Data of heat and moisture transport and storage parameters is given in Table 4.

Table 3. Basic structural and mechanical properties of studied composites.

Composite	ρ_b **(kg·m^{-3})**	ρ_s **(kg·m^{-3})**	ψ **(%)**	f_f **(MPa)**	f_c **(MPa)**
MGR	2 005	2 409	16.80	14.2	55.7
MGS	1 499	2 124	29.40	14.0	44.2
MGSH	1 411	2 107	33.00	10.8	40.4

The use of foam glass aggregate significantly increased composite total open porosity in the comparison with the control material. The experimentally assessed values of the tested mechanical parameters corresponded to the specific density and total open porosity data. The replacement of silica sand with foam glass caused a decrease in both the compressive and flexural strengths.

Table 4. Heat and moisture transport and storage parameters.

Composite	$\boldsymbol{\lambda}$ **($\mathbf{W \cdot m^{-1} \cdot K^{-1}}$)**	$\boldsymbol{c_v} \times \mathbf{10^6}$ **($\mathbf{J \cdot m^{-3} \cdot K^{-1}}$)**	$\boldsymbol{A_w} \times \mathbf{10^{-2}}$ **($\mathbf{kg \cdot m^{-2} \cdot s^{-1/2}}$)**	$\boldsymbol{D} \times \mathbf{10^{-8}}$ **($\mathbf{m^2 \cdot s^{-1}}$)**	$\boldsymbol{\mu}$ **(-)**
MGR	2.50	2.20	0.538	6.20	457
MGS	0.90	1.70	1.500	0.20	212
MGSH	0.80	1.70	0.260	5.50	588

The thermal conductivity and volumetric heat capacity data presented in Table 4 declared the reduction of these parameters by use of foam glass granulate. It was attributed to its high porosity. The reduction of heat transport and storage parameters was clearly visible, which is for the thermal insulation materials highly important (Záleská *et al.* 2018). Since capillary water content was difficult to determine, only the water absorption coefficient was calculated from the linear part of the water sorptivity dependence. One can see the increase in water absorption due to porous aggregate usage and distinct decrease, when the inner hydrophobization was applied. The values of water vapor transmission parameters obviously pointed to the influence of the use porous aggregate in MGS composite and application of inner hydrophobic agents in the case of MGSH composite. From this point of view, the usage of inner hydrophobization could lead to the improvement of water resistance of MOC-based composites.

4 CONCLUSIONS

Foam glass aggregate was studied as a full replacement for silica sand in composition of MOC-based composites. The composites with incorporated light-weight foam glass aggregate exhibited sufficient mechanical resistance and improved thermal insulation function. Lower water absorption in the case of inner hydrophobization usage is promising for durability of MOC composites with respect to harmful water action. In this sense, low thermal conductivity and improved moisture resistance permit usage of these developed composites as thermal insulation floors, ceiling or wall panels reducing the energy performance of buildings.

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