MECHANICAL AND HYGRIC PROPERTIES OF FGD GYPSUM MODIFIED BY SECONDARY RAW MATERIALS




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Summary

Measurements of basic mechanical and hygric parameters of calcined gypsum produced from waste flue gas desulfurization (FGD) gypsum and modified by the addition of two different types of secondary raw materials, namely fly ash and milled gypsum are presented in the paper. Bulk density, matrix density, open porosity, water absorption coefficient, apparent moisture diffusivity, moisture diffusivity as function of moisture content and bending and compressive strength are determined and compared to the properties of hardened gypsum without any admixtures.

Keywords: FGD gypsum, secondary raw materials, hygric properties, mechanical properties

1 Introduction

Calcined gypsum is a historical binder that was used already several thousands years ago. In the second half of the 20th century, there were developed technologies for desulfurization of flue gases in power stations and heating plants. In Czech Republic, calcined gypsum is produced from flue gas desulfurization (FGD) gypsum only in one power station (Počerady), the remaining production ends with gypsum that is used only partially as additive retarding the setting of cement. The utilization of FGD gypsum is insufficient considering the amount of its production. Therefore, it is very desirable to pay attention to utilization of calcined gypsum also in such applications where it was not used yet. For modification of utility properties of FGD gypsum can be used different types of aggregates, historical aggregates for gypsum binder were paper, rushes or animal fur [1]. Now, common building materials including recycled ones are used. Herándes-Olivares et al. [2] determined properties of cork-gypsum composites for building applications. Verbeek and du Plessis [3] modified phosphorgypsum-polymer composite by vermiculite. Murat and Attari [4] used different types of clay minerals as aggregates for gypsum. Ghozh et al. [5] determined dependence of flexural and compressive strength on water/gypsum ratio for samples on gypsum-perlite base. Singh and Garg [6] explored relationship between mechanical properties and porosity of water resistant gypsum binder, which consisted of phosphorgypsum, slag and Portland cement. In this paper, two different types of secondary raw materials, namely fly ash and milled gypsum, are used as aggregates with waste flue gas desulfurization (FGD) gypsum as binder.

2 Experimental methods

Basic physical properties, namely bulk density, matrix density and open porosity, were measured by water vacuum saturation method.

The apparent moisture diffusivity was determined from a 1-D water sorption experiment. The specimen was water and vapor-proof insulated on four lateral sides and the face side was immersed 2 mm in the water. Automatic mass recording enabled determination of water sorptivity and consequently of apparent moisture diffusivity.

The water vapor diffusion coefficient was determined using the dry cup method for the values of relative humidity of 5 and 30 %. The measurements were done at 25 °C in a period of two weeks. The steady state values of mass gain determined by linear regression for the last five readings were used for the determination of water vapor flux.

The capacitance method [7] was employed to the measurement of moisture content; the measuring frequency was 250 – 350 kHz. The moisture profiles were determined using a common capillary suction 1-D experiment in the horizontal position, lateral sides of specimens were water and vapor-proof insulated. Moisture meter reading along the specimen was done every 5 mm. The calibration curve was determined after the last moisture meter reading, when the moisture penetration front was at about one half of the length of the specimen, using this last reading and the standard gravimetric method. The final calibration curve for the material was constructed from the data of 6 samples. The moisture profiles were then calculated from the calibration curve. Moisture diffusivity was determining by the Matano method [8].

The measurement of bending strength was performed according to the Czech standard ČSN 72 2301 [9] on the 40 x 40 x 160 mm samples. The specimens were demolded 15 minutes after the final setting time and stored in the testing room. The experiment was performed as a common three-point bending test. The distance of the supporting cylinders was 100 mm. The measurements were done at the times of 2 hours (standard time), 1 day, 3 days, 7 days, 14 days and 28 days after mixing. Compressive strength was on the halves of the specimens left over after the bending tests. The specimens were placed between two plates; the load area was 40×40 mm.

3 Materials and samples

β-form of calcined gypsum with purity higher than 98 % of FGD gypsum, produced at the electric power station Počerady (Czech Republic), was used for measurements. The water/gypsum ratio of 0.627 corresponding with the normal consistence according to the Czech standard ČSN 72 2301 [7] was chosen for specimen preparation. Reference gypsum material with this water/gypsum ratio was denoted as S0. Two different types of fillers were used, both of them being secondary raw materials. The first filler was fly ash produced by high-temperature combustion in ironworks in Třinec (the gypsum mixture with these aggregates was denoted as S9), with the following composition as amount of % by mass: SiO_2 44.98, Al_2O_3 22.72, Fe_2O_3 8.81, CaO 4.31, MgO 2.96, K_2O 2.84, Na_2O

0.49 and SO_3 0.64. The other one was milled gypsum from Počerady power plant (gypsum mixture denoted as S10). The exact composition of the particular gypsum mixtures is given in **Tab. 1**.

Tab. 1 Composition of gypsum mixtures

Material	Aggregates	Amount of aggregates [g]	Amount of gypsum [g]	Amount of water [g]
S0	None	-	1000	627
S9	Fly ash	300	700	627
S10	Milled gypsum	300	700	627

4 Experimental results

The basic properties of studied materials are presented in **Tab. 2**. The bulk density significantly decreased due to the application of fly ash (S9). The open porosity followed an opposite trend.

Tab. 2 Basic properties

Material	Bulk density [kg m^{-3}]	Matrix density [kg m^{-3}]	Open porosity [% by volume]
S0	1180	1800	38
S9	1076	1777	39
S10	1160	1815	36

Comparison of basic hydric properties shows **Tab. 3**. The calculated water absorption coefficients and apparent moisture diffusivities show that the fastest water absorption exhibited the material S9 with fly ash. This is in a good qualitative agreement with the basic properties data in Table 2. The apparent moisture diffusivity of the material S9 with fly ash was about 50 % higher in a comparison with other materials. The water vapor diffusion was fastest in the materials S9 and S10 (see **Tab. 3**).

Water and water vapour transport properties

Material	Water absorption coefficient [kg m^{-2} s$^{-1/2}$]	Apparent moisture diffusivity [m^2 s^{-1}]	Water vapour diffusion resistance factor [-]
S0	0.30	7.13 E-07	13.8
S9	0.42	1.10 E-06	8.9
S10	0.32	7.00 E-07	8.6

Fig. 1 shows dependence of moisture diffusivity on moisture content for the studied materials. The measured results achieved a good qualitative agreement with the measurements of apparent moisture diffusivities in **Tab. 3**. The moisture diffusivity of the material S9 was significantly higher than that of the two remaining materials. The apparent moisture diffusivity corresponded with the values of moisture dependent moisture diffusivity determined for higher moisture content, typically about 80 % of water saturation value.

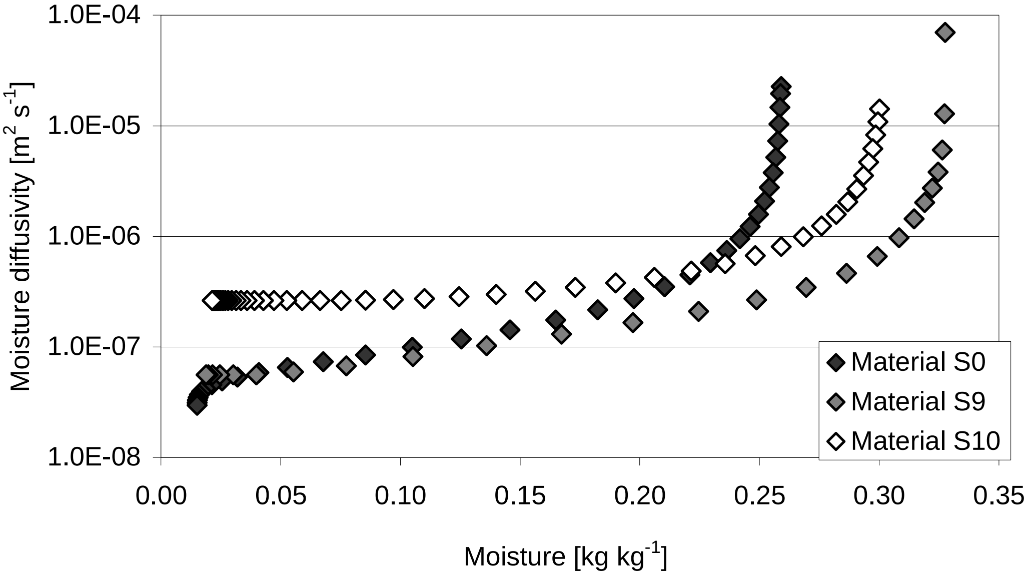

Fig. 1 Dependence of moisture diffusivity on moisture content

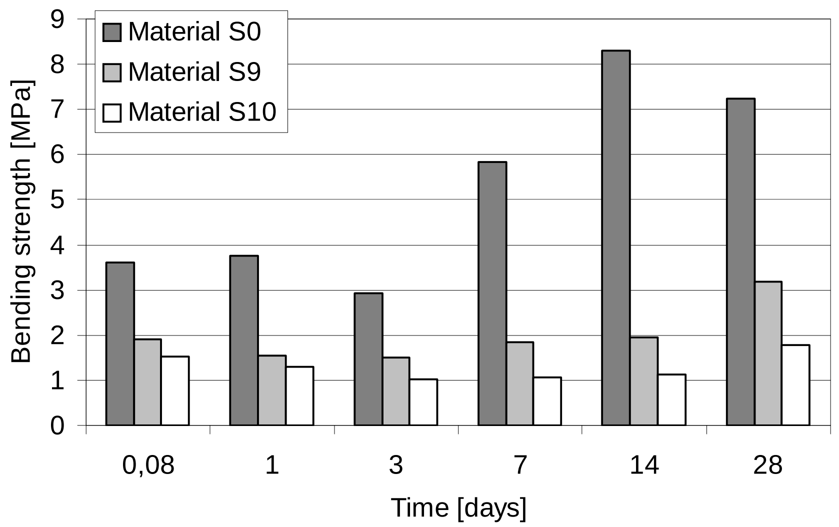

Fig. 2 Bending strength

Figs. 2 and **3** show a comparison of basic mechanical properties of the studied materials. Both compressive strength and bending strength of the materials with aggregates were significantly lower than for the reference material without aggregates. This feature was for later times more distinct than for initial times so that after 28 days the strength values for the reference material were three to five times higher than for any of the materials with aggregates. A comparison of mechanical properties with the basic properties does not show any correlation of compressive strength with bulk density and porosity. One of the possible explanations of the decrease of strength values for materials with aggregates is a lower effectiveness of the gypsum hydration process in relation to the formation of firm crystalline structure or a bad contact between the binder and the aggregates. The lower amount of gypsum, thus higher water/gypsum ratio in the materials with aggregates can be another reason.

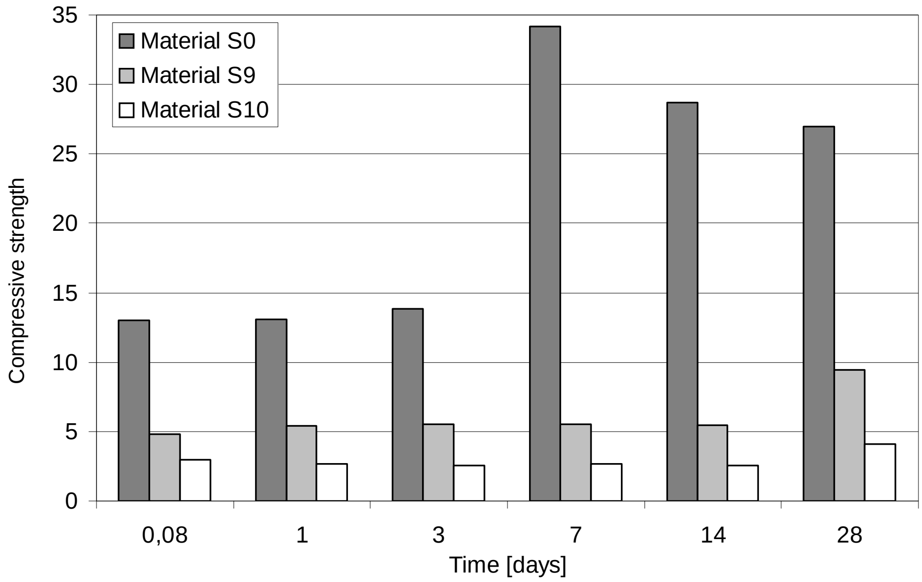

Fig. 3 Compressive strength

5 Conclusions

The presence of two different types of secondary raw-materials used as aggregates in FGD gypsum-based materials affected mechanical and hygric properties analyzed in this paper in a very significant way. The most important finding was the remarkable decrease of both compressive and bending strength in a comparison with the reference material without aggregates which was not in any relation to the changes of bulk density and porosity. The hygric properties of both studied materials were in a basic qualitative agreement with bulk density and porosity so that it can be concluded that the effect of aggregates satisfied the basic intentions of their use in this respect.

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