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DEPENDENCE OF MECHANICAL AND THERMAL PROPERTIES ON THE COMPOSITION OF LIGHTWEIGHT GYPSUM COMPOSITES

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Abstract. One of the ways to use the treated gypsum waste is in gypsum mixtures for the production of gypsum blocks. Gypsum blocks can be used in standard interior as well as exterior applications and are made of gypsum, water, PP microfibres and are lightened with foam, which is created from a foaming additive and water. Above all, the amount of foam significantly influences the bulk density of the resulting material, and the bulk density then has a major influence on the mechanical and thermal properties. The use of PP microfibres had a positive effect on the overall stability of the foamed structure, which resulted in an increase in compressive strength while maintaining good thermal insulation properties.

Keywords: Mechanical properties, thermal properties, gypsum, lightweight composite.

1. Introduction

The trend nowadays is to use recycled materials generated in the construction industry and reuse them in the construction industry. In this way, mineral resources are protected and there is no need to extract new non-renewable raw materials. Such materials include gypsum, which is up to 100 % recyclable. One of the most common uses of gypsum today is primarily in the manufacture of plasterboard (PB). The issue of recycling of construction PB is related to its contamination with PB of different types from different manufacturers (different compositions) and other materials used in the production of PB structures – dry constructions [1, 2]. These include mineral insulation, metal profiles, PUR foams, residues of wipers, etc. Another problem is related to the biodegradation of PB [3–5].

The above contamination complicates the return of this material for PB re-manufacturing, which is quite demanding in terms of the quality of the input recycled material, technological processes, etc. Therefore, efforts are made to find suitable materials and products based on recycled construction PB that are not so susceptible to changes in the quality of PB recyclate [6, 7].

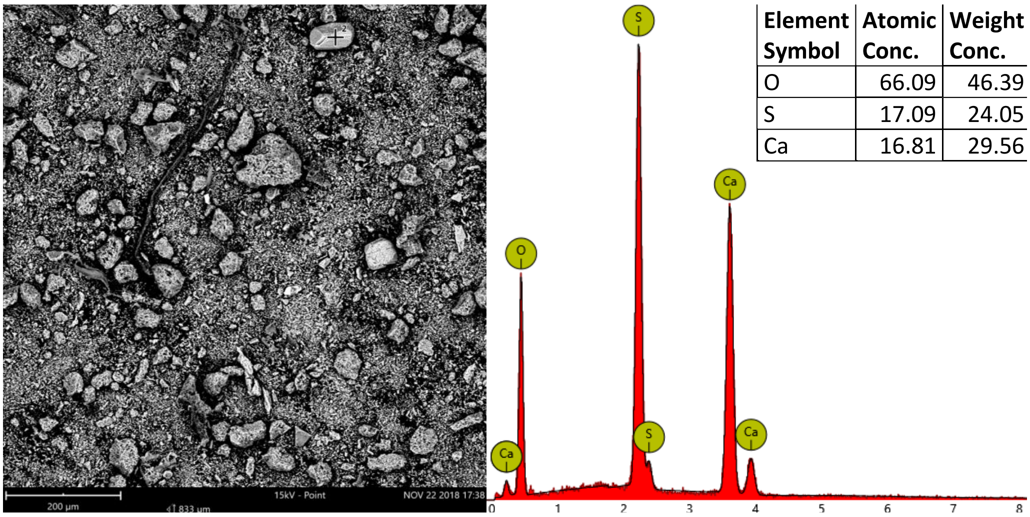
One way to use recycled PB is in the form of lightweight blocks to be used for building envelopes. Blocks for building envelopes today are primarily designed to have a certain balance between mechanical properties (primarily compressive strength, modulus of elasticity, etc.) and thermal performance. The most commonly used thermo-technical parameter is the thermal conductivity coefficient, which can then be used to calculate the thermal resistance and possibly other characteristics that are already part of the building design or an optimal envelope composition. The composition is possibly supplemented by thermal insulation materials.

The advantage of gypsum-based materials is the fact that the gypsum can be modified, either by additives and admixtures, to modify the resulting performance of the hardened material. The primary objective in the design of a new gypsum mixture (dry or wet) is to modify the internal structure (in terms of internal arrangement and ratio of mass and excitatory pores), and thus to change the bulk density of the fresh gypsum slurry, i.e. of the hardened and subsequently dried samples, where the mixture/material/product already has the resulting material properties [8–10].

In terms of achieving optimal mechanical properties (compressive strength) and thermal properties (thermal conductivity coefficient), these are completely opposite effects. In terms of compressive strength, we need a material with a minimum number of pores and, conversely, for the thermal conductivity coefficient, we would need a material full of small pores to make the whole structure lighter. At first glance, quite different properties and requirements can be achieved with the optimum ratio of the components used – water, gypsum or gypsum primary inert binder, using a foaming additive and microfibres. In general, chemical additives such as setting retardant, plasticizing additive, etc. can be used. A properly applied foaming additive (in terms of the amount of foaming additive, the

(a). Demolition of a plasterboard wall.
(b). Waste inside the smart container.
(c). Typical waste after emptying from the container.

Figure 1. Demolition of a plasterboard wall, waste inside the smart container, typical waste after emptying from the container, in this case green.



Element Symbol	Atomic Conc.	Weight Conc.
O	66.09	46.39
S	17.09	24.05
Ca	16.81	29.56

Figure 2. Chemical analysis of recyclate by SEM EDS analysis.

amount of water, the quality and stability of the foam) will lighten the gypsum matrix, ideally by small pores that do not clump and are evenly distributed throughout the volume of the mass, and the microfibres will “hold” the entire foamed and lightened structure during the initial stages of setting and hardening and will also improve the resulting mechanical properties.

Another advantage of the whole concept of producing gypsum blocks based on recycled gypsum waste is that waste from the production of gypsum blocks can be incorporated into the mix as a primarily inert material. A further advantage is the fact that when the gypsum blocks are refurbished or end-of-life, they can be reused or recycled again and used for the production of new blocks [11].

2. Materials and samples

The composites were composed of recycled PB materials. The recyclate came from the construction site, was sorted using a “smart” container and contained mainly “ordinary” white (grey) PB from Knauf Praha, spol. s. r. o. (Figure 1). Construction PB waste was treated on a mobile recycling line at Lavaris s. r. o. in Libčice nad Vltavou. The treated PB recyclate was delivered to the Faculty of Civil Engineering of the Czech Technical University in Prague in closed plastic cans.

At the Faculty of Civil Engineering, analysis of this material was carried out using a Pheonom XL scanning electron microscope. The recyclate was examined using a BSE detector in combination with EDS analysis (Figure 2). The results show that the purity of the recyclate is greater than 95 % of $CaSO_4$.

From the point of view of efficient utilization and verification of the technological possibilities of production of lightweight blocks in laboratory conditions, it was advisable that the calcination rate was as high as possible, for this reason a selected part of the imported PB recyclate was further calcined to achieve at least 95 % calcination rate of the total weight of the recyclate samples, based on the weight of the binder, i.e. including any impurities. The calcination was carried out under laboratory conditions using a laboratory oven heated to 120 °C until the mass was stable, corresponding to the evaporation of water or the stoichiometric difference between the calcined

Samples	Plaster [g]	Water [g]	W/P [-]	Fibres [g]	Type of Foam	Foam addition [g]
F	3.0	2.1	0.7	0	None	0
G	3.0	2.1	0.7	15	None	0
H	3.0	1.8	0.6	15	In-situ	60
I	3.0	1.8	0.6	15	In-situ	45
J	3.0	1.8	0.6	0	In-situ	30
K	3.0	1.8	0.6	15	In-situ	30
L	3.0	1.8	0.6	15	In-situ	15

TABLE 1. Used mixtures and their composition.

gypsum and the gypsum. The degree of calcination was verified on selected samples using so-called drying scales.

To ensure the stability of the foamed structure, specially manufactured PP microfibres from Trevos were used. Microfibres have 32 µm in diameter and 4 mm in length. Other properties are following: average tensile strength, ≤3.0 cN/dtex (∼272 MPa); average elongation, ≤50 %; density, 910 kg/m^3; Young modulus of elasticity, ∼4 GPa.

Based on previous experiments, several sets of gypsum-based specimens were designed to verify the dependence of water coefficient and foam amount on the final properties of the lightweight gypsum composites. For comparison purposes, reference sets without lightening (F and G) were also created to better identify the degree of lightening and compositional adjustment. Other sets were specific in the amount of foaming agent used (15, 30, 45 and 60 g). The foam was produced so-called caused in-situ. Some sets additionally contained PP microfibres. For practical reasons, a water coefficient of 0.7 had to be used for sets F and G, and for the other sets it was reduced to 0.6. For each set, 6 cubes with an edge of 100 mm were made. See Table 1 for details.

3. Experimental methods

Prior to testing, all the test samples were artificially dried at 40 °C using a hot air oven for 3 days until the weight stabilized. They were then stored in a desiccator at laboratory temperature and 0 % humidity for 24 hours. The samples thus prepared were subsequently tested.

First, the samples were tested to determine the bulk density and thermal properties. Testing of thermal properties was performed on heat transfer analyzer ISOMET 2104 (Applied Precision) equipped with surface probe API210411 and API210412. The investigated thermal property was the thermal conductivity coefficient λ. The surface probes had measuring range from 0.04–0.3 W/mK, and 0.3–2.0 W/mK, and accuracy of ±5 % was used. Such a device applies a dynamic method which is based on response monitoring of examined material on heat flow impulses. Measurements were made on 100 × 100 × 100 mm samples and each measurement was made on a different side of the cube. Each sample was measured three times and the resulting value was averaged and the standard deviation determined. The temperature of the samples during the measurement was equal to 22±1 °C (the same as ambient air).

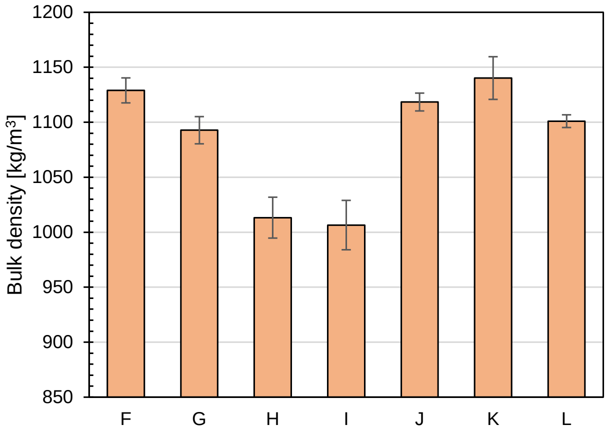


FIGURE 3. Comparison of the average values (with standard deviations) of the bulk density of the tested gypsum mixtures.

Finally, destructive tests were performed. The destructive tests were carried out using a Heckert FP100 loading frame with displacement-controlled loading at 0.1 mm/min. A uniaxial compression test was carried out on cubic samples. Compressive strength was calculated from the maximum force reached during the test, $F_{c,max}$, as:

$$f_c = \frac{F_{c,max}}{ab}. \quad (1)$$

4. Experimental results

After the solidification and hardening process, a porous system was formed in the hardened gypsum mass, which defines the bulk density. After drying the samples from the water necessary for processing (from a technological point of view), the value of the bulk density of the naturally wet gypsum solid structure was determined. The comparison of the average bulk density values in Figure 3 shows the influence of the fibers between sets F and G. The lowest value was measured for sets I and H with the highest amount of foaming additive added, while the lowest value was measured for set K.

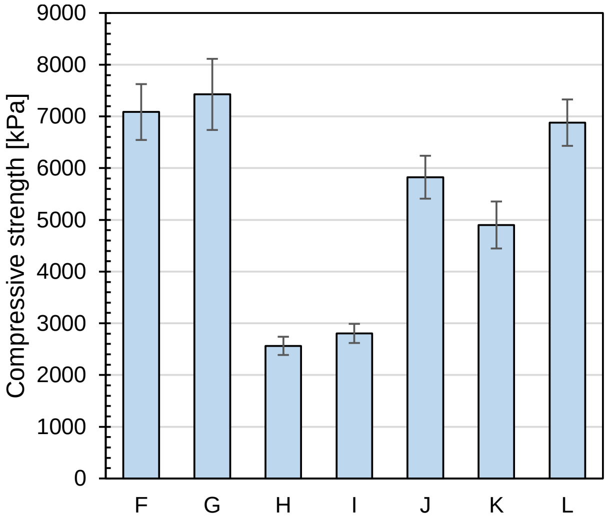


FIGURE 4. Comparison of the average values (with standard deviations) of the compressive strengths of the tested gypsum mixtures.

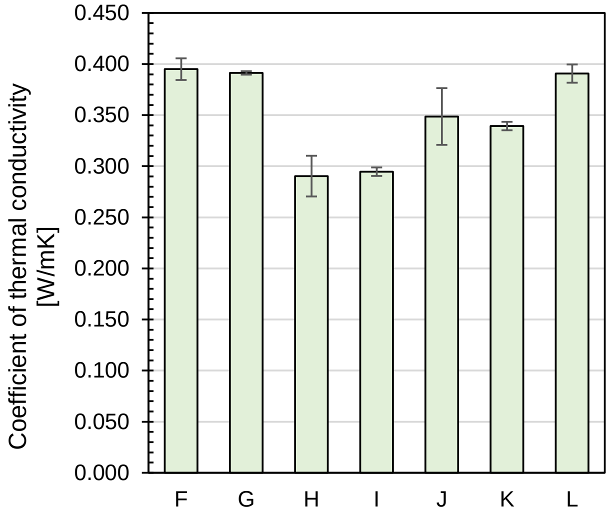


FIGURE 5. Comparison of the average values (with standard deviations) of the thermal conductivity coefficient of the tested gypsum mixtures. The values were determined for naturally moist samples in a laboratory environment at a temperature of 25±2 °C and a relative humidity of 50±3 %.

Figure 4 compares the average compressive strengths. The highest average values were obtained for the reference samples F and G without foaming, but a value below 7 MPa was also obtained for set L with 15 g of foaming additive and PP fibres. The lowest average values were obtained for set H and I, where their values fell below 3 MPa.

Figure 5 compares the average thermal conductivity coefficient values for the tested gypsum mixtures. In terms of this parameter, set K with 30 g of foaming additive and PP fibres has the worst values around 0.5 W/mK. The best average value of 0.35 W/mK was measured for sets H and I. For most of the other sets, values around 0.4 W/mK were obtained.

5. Conclusions

The paper presents the first part of the results in the field of effective use of treated gypsum plasterboard waste treated by a recycling line and its subsequent use in the form of lightweight blocks for building envelopes. The described reuse method seeks to efficiently use the gypsum plasterboard recyclate and transform it into a new building product that can compete with conventional materials, such as the classic aerated concrete blocks that are commonly used today.

Calcination was also verified in the laboratory using a laboratory dryer at temperatures up to 120 °C. In the next part of the project, the aim will be to add a new calcination unit to the recycling line, which would effectively refine the treated plasterboard recyclate and convert it into a gypsum binder with similar properties to a conventional building plaster.

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