Properties of gypsum composites with shavings

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Abstract. Gypsum composites have been gaining increasing interest within last decades. Nowadays, the environment-supporting options are regaining more advocates. Among other solutions, organic fillers are of interest. The physical and mechanical properties of gypsum composites with shavings were tested and are described in the paper. The influence of gypsum mixture composition, the water/gypsum ratio and appropriate mineralization on the composite properties were examined. Present study focuses on the durability, thermal properties, natural radioactivity and susceptibility to biological corrosion of gypsum composites with shavings.

1. Introduction
There is a growing popularity of the advanced, modern constructing materials [1, 2], especially those based on the gypsum composites [3]. They have been gaining increasing interest within last decades, especially in Poland, where the rich, countrywide natural gypsum sources and the growing amounts of synthetic gypsum derived from flue gas desulfurization in domestic power plants can be found.

Thermal and sound-proofing properties of those materials are widely known and can be additionally improved by increasing the porosity. This can be achieved by foaming or adding pore-forming organic or non-organic agents. Different fillers can be added to gypsum plaster in order to modify its physical properties. Properly applied additives can improve physical and thermal conductivity (expanded silica gel granules) or reinforce the structure (glass fibers, carbon fibers etc.).

Nowadays, the environment-supporting options are regaining more advocates. Thus, organic fillers, represented by shavings are back in game. This raw and easy-accessible material can be additionally mineralized to create the desired physical and mechanical properties of the building material. This, apart from protection against biological corrosion, facilitates compacting of gypsum mixtures during the formation of samples for laboratory tests.

There are three different methods of gypsum composites production: pouring, casting and underwater method, where pouring is recognized as the most advantageous method applied in researches. It allows determination of the interrelation between the properties of hardened composites and the composition and physical properties of gypsum mixtures. Moreover, this method ensures more uniform distribution of filler’s particles.

2. Methodology
In the present study, the pouring method was applied with 16 technological recipes. Shavings were delivered from a carpentry workshop after softwood processing. Prior to the experiments, this raw material was sieved through 6 and 1 mm screens to remove organic material and thick particles.
The bulk density of the filler in the air-dry condition was:

- 44 kg / m³ while loose,
- 60 kg / m³ while compacted.

The gypsum was the semi-water gypsum of the "Nida Valley" Gypsum Factory. The content of shavings in the mixtures was respectively 8, 10, 12 and 14%, which, in relation to the weight of gypsum, constituted 14.8 - 32.5%. Three different water/gypsum ratios (W/G) were applied: 0.7, 0.8, 0.9 and 1.0. Both the non-mineralized shavings and the shavings after mineralization with CaCl₂, Ca(OH)₂ and Al₂(SO₄)₂, were used.

The test samples of gypsum composites have been prepared according to the following scheme:

- beams 4 x 4 x 16 cm for partial tests;
- cubes 10 x 10 x 10 cm for full tests.

Scope of partial tests:

- bending strength in Michaelis apparatus;
- compression strength on beams’ halves on laboratory press, type PLH-12/4-WK-54;
- apparent density in the air-dry condition and after drying to a constant mass.

Only the selected, non-mineralized samples, which proved to present the compressive strength over 3MPa in the partial tests, were utilized further in the full tests.

The full tests included: mass absorbability, softening coefficient and thermal conductivity coefficient.

The conductivity coefficients were determined on the disk-shaped samples with the diameter of 10 cm and thickness of 2 cm, in so-called “lambda meter” (Compact Unit for Lambda Coefficient Measurement).

The samples of gypsum composites were formed of mixtures containing the shavings fillers without mineralization as an initial material for further comparative tests with a series of samples containing mineralized organic material.

5% water solutions of calcium chloride, calcium hydroxide and aluminium sulphate were used for mineralization. The commonly accepted manner of mineralization was applied, treating these solutions as make-up water.

In addition to that, the microbiological tests of the samples have been conducted, due to a potential hazard of biological corrosion of the composites. 10 g of the examined material was prepared and poured with sterile distilled water. After 15 minutes the sample was applied on a sterile substrate. Standard, selective substrates for culturing bacteria, fungi, algae and protozoa, were applied. After appropriate time, the quantities of microbes were assessed.

The natural radioactivity of the samples was also examined. [4-10]

3. Results and discussion
The results of conducted physical and mechanical tests are presented in Tables 1, 2 and 3. The results of the microbiological analysis are presented in Table 4.
Results of partial tests for the samples of gypsum composites with non-mineralized shavings

| Sample no. | Substance content [\%] | Quantity of filler in relation to gypsum mass [\%] | W/ G | W/ m, | Apparent density [kg/m³] | Strength [MPa] |
|------------|-------------------------|-----------------------------------------------|------|------|--------------------------|---------------|
|            | gypsum | filler | water | 14,8 | 0,7 | 0,61 | 1441 | 1054 | 3,22 | 5,89 |
| 1          | 1      | 1      | 38    | 14,8 | 0,7 | 0,59 | 1393 | 1013 | 6,42 | 4,61 |
| 2          | 1      | 1      | 36    | 23,0 | 0,7 | 0,57 | 1290 | 855  | 6,18 | 3,59 |
| 3          | 1      | 1      | 35    | 27,4 | 0,8 | 0,55 | 1236 | 1236 | 3,22 | 3,73 |
| 4          | 1      | 1      | 41    | 15,7 | 0,8 | 0,69 | 1465 | 956  | 5,66 | 3,41 |
| 5          | 1      | 1      | 40    | 20,0 | 0,8 | 0,66 | 1412 | 942  | 5,36 | 3,40 |
| 6          | 1      | 1      | 39    | 24,5 | 0,8 | 0,64 | 1352 | 802  | 6,63 | 3,15 |
| 7          | 1      | 1      | 38    | 29,2 | 0,8 | 0,62 | 1370 | 817  | 4,73 | 3,56 |
| 8          | 1      | 1      | 44    | 16,7 | 0,9 | 0,77 | 1365 | 875  | 4,96 | 3,25 |
| 9          | 1      | 1      | 43    | 21,2 | 0,9 | 0,74 | 1344 | 873  | 4,65 | 2,87 |
| 10         | 1      | 1      | 42    | 26,0 | 0,9 | 0,71 | 1321 | 774  | 5,54 | 3,25 |
| 11         | 1      | 1      | 41    | 31,0 | 0,9 | 0,69 | 1240 | 758  | 5,82 | 3,20 |
| 12         | 1      | 1      | 40    | 17,4 | 1,0 | 0,85 | 1250 | 703  | 5,06 | 4,29 |
| 13         | 1      | 1      | 39    | 22,2 | 1,0 | 0,82 | 1234 | 709  | 4,75 | 3,17 |
| 14         | 1      | 1      | 38    | 27,2 | 1,0 | 0,79 | 1234 | 709  | 5,07 | 2,80 |
| 15         | 1      | 1      | 43    | 32,5 | 1,0 | 0,75 | 1268 | 703  | 4,16 | 3,36 |

Table 2. The bending and compression strengths in samples with and without mineralization

| Sample no. | W/ G | Quantity of filler in relation to gypsum mass [\%] | Strength of samples depending on the process of mineralization of the filler | Bending strength [MPa] | Compression strength [MPa] |
|------------|------|-----------------------------------------------|-----------------------------------------------|-------------------------|---------------------------|
|            |      |                                               | Without mineralization | CaCl₂ | Ca(OH)₂ | Al₂(SO₄)₃ | Without mineralization | CaCl₂ | Ca(OH)₂ | Al₂(SO₄)₃ |
| 1          | 0,7  | 14,8                                          | 3,22, 2,90, 2,80 | 3,50 | 5,89 | 6,00 | 6,05 | 6,10 |
| 2          | 0,7  | 18,8                                          | 6,42, 2,80, 2,70 | 3,10 | 4,61 | 6,34 | 6,70 | 6,80 |
| 3          | 0,7  | 23,0                                          | 6,18, 2,86, 2,90 | 3,15 | 3,59 | 6,00 | 6,90 | 6,90 |
| 4          | 0,7  | 27,4                                          | 3,22, 2,76, 2,82 | 4,00 | 3,73 | 6,28 | 6,00 | 7,20 |
| 5          | 0,8  | 15,7                                          | 5,66, 2,40, 2,55 | 2,75 | 3,41 | 4,00 | 4,70 | 5,20 |
| 6          | 0,8  | 20,1                                          | 5,36, 2,55, 2,70 | 2,70 | 3,40 | 4,40 | 4,80 | 4,92 |
| 7          | 0,8  | 24,5                                          | 6,63, 2,58, 2,75 | 3,00 | 3,15 | 4,52 | 4,70 | 4,90 |
| 8          | 0,8  | 29,2                                          | 4,73, 2,30, 2,50 | 3,05 | 3,56 | 4,58 | 4,20 | 5,15 |
| 9          | 0,9  | 16,7                                          | 4,96, 2,20, 2,40 | 2,60 | 3,25 | 2,70 | 2,90 | 3,00 |
| 10         | 0,9  | 21,2                                          | 4,63, 2,24, 2,20 | 2,56 | 2,87 | 2,85 | 3,10 | 3,14 |
| 11         | 0,9  | 26,0                                          | 5,54, 2,10, 2,45 | 2,60 | 3,25 | 3,31 | 3,40 | 3,30 |
| 12         | 0,9  | 31,0                                          | 5,82, 2,35, 2,50 | 2,40 | 3,20 | 3,80 | 4,00 | 3,80 |
| 13         | 1,0  | 17,4                                          | 5,06, 2,00, 2,30 | 2,45 | 4,29 | 2,50 | 2,60 | 2,65 |
| 14         | 1,0  | 22,2                                          | 4,75, 1,9, 2,35 | 2,40 | 3,17 | 2,55 | 2,60 | 2,70 |
| 15         | 1,0  | 27,2                                          | 5,07, 2,15, 2,20 | 1,90 | 2,80 | 2,60 | 2,40 | 2,70 |
| 16         | 1,0  | 32,5                                          | 4,16, 2,10, 2,00 | 1,95 | 3,36 | 2,74 | 2,85 | 2,82 |
Table 3. Results of full tests for gypsum composite samples with non-mineralized shavings

| Sample no. | Quantity of filler in relation to gypsum mass [%] | W/G | Compression strength | Mass absorptivity % | Softening coefficient | Thermal conductivity coefficient [W/m x deg] |
|------------|--------------------------------------------------|-----|----------------------|---------------------|-----------------------|---------------------------------------------|
| 0*         | -                                                | 0,65 | 7,60                 | 35                  | 0,36                  | 0,66                                        |
| 5          | 15,7                                             | 0,8  | 3,40                 | 46                  | 0,25                  | 0,45                                        |
| 6          | 20,0                                             | 0,8  | 3,35                 | 53                  | 0,20                  | 0,42                                        |
| 13         | 17,4                                             | 1,0  | 4,20                 | 77                  | 0,21                  | 0,42                                        |
| 14         | 22,2                                             | 1,0  | 3,10                 | 62                  | 0,23                  | 0,42                                        |
| 15         | 27,2                                             | 1,0  | 3,00                 | 69                  | 0,25                  | 0,43                                        |
| 16         | 32,5                                             | 1,0  | 3,30                 | 70                  | 0,30                  | 0,42                                        |

* sample made of gypsum without fillers

Table 4. Microbiological analysis of shavings and gypsum composites with filler

| No. | Kind of microorganisms | Incubation time [h] (temp. °C) | Shavings (JTK/g) | Gypsum composite with filler (JTK/g) |
|-----|------------------------|--------------------------------|------------------|-------------------------------------|
| I   | Bacteria:              |                                |                  |                                     |
|     | 1. Psychrophilic       | 72h (20°C)                     | 100              | 700                                 |
|     | 2. Mesophilic          | 24h (37°C)                     | 20               | 5                                   |
|     | 3. Autotrophic         | 72h (20°C)                     | 20               | 10                                  |
| II  | Fungus                 | 120h (20°C)                    | 5000             | 80                                  |
| III | Protozoa               | 96h (20°C)                     | none             | none                                |

The analysis of various gypsum composites revealed huge impact of the mineralization on the mechanical properties of samples. The non-mineralized shavings, applied as a filler, led to the highest bending strength values, while mineralization caused significant decrease of this parameter. Although, the compression strengths show the opposite tendency, with the highest values in mineralized samples. The values appeared to be independent from the type of mineralization. This might be due to the general easier thickening of the mixture in the molds, while mineralized shavings allow to achieve more dense samples. This tendency is best expressed within the gypsum composites with the low W/G ratio.

Looking deeper into compression strengths reveals that aluminium sulphate provides the most successful enforcement, and it increases even with the maximal shavings’ concentration in the mixture. Mineralization provided with calcium hydroxide allows to enforce the composite until shavings’ content reaches 23-24.5%. Nonetheless, with higher concentrations it instantly decreases. Calcium chloride application impacts the mechanical strength the least, however it does not cause the abrupt changes after increasing the filler content or W/G ratio.

The water/gypsum ratio impacts the composite’s properties as predicted. Along with its increase, the ostensible density of the mixture diminishes. Nevertheless, this phenomenon isn’t associated with the significant mechanical durability deterioration. This might be due to the natural tendency of the organic filler to drain the mixed water more than the mineral fillers. Taking into consideration the ratio of water content to the dry compounds mass (gypsum + filler), the index varies between 0.55-0.88, which may form the main cause of the slight differences in composites’ strengths despite the high filler content.
Along with the W/G ratio increase from 0.8 to 1.0, the absorptivity raises up to 50%-77%.

In present study, the content of shavings was 15.7-32.5% in relation to the dry gypsum mass. This amount of organic filler in composite increases the absorptivity, however it also improves its thermal conductivity coefficient (from 0.66 to 0.42-0.45).

Both the samples of filler and gypsum composites with this filler were subjected to the tests for the presence of bacterial flora. The pH of the shavings (5.5) mixed with pure gypsum (8.5) reached 7.2, therefore the conditions were assessed to be beneficial for the development of bacterial flora. Following microbiological tests have been conducted.

Fungi formerly present in the shavings (5000 JTK/g), significantly decreased after gypsum addition (80 JKT/g). Mesophilic bacteria, the organisms that grow best in the moderate temperatures, are present in a small amount, which additionally decreases after addition of gypsum paste. The colonies of psychrophilic bacteria, who are capable of growth in extreme temperatures, and autotrophic bacteria, who produce by themselves the complex organic compounds, were noted to enlarge slightly in gypsum composites. Nevertheless, detected organisms are claimed not to pose any hazard of biological corrosion for examined materials.

The natural radioactivity of the gypsum composite was assessed to meet the requirements of radioactive elements concentration. Radioactivity reached 7.5 Bq/kg, which is 4.1% of maximum permissible value.

Gypsum composites containing sawdust can be widely used in construction. Including the high percentage of filler is an inexpensive and effective way to create the light construction elements, while sawdust is highly available as a waste of wood processing. [11, 12]

4. Conclusions

Gypsum composites with the organic shavings filler (8-14%) mineralized with Ca(OH)2 are decreasing the mechanical strength of material. Therefore, other mineralizers, like CaCl2 or Al2(SO4)2 are more favourable with their ability to increase the bending and compressing strength.

The compression strength for most samples reaches 3 MPa, although with the higher W/G ratio (1.0), the decrease in the strength is noted.

Despite the significant differences between the filler content percentage (14.8 - 32.5%) and W/G ratio (0.7 - 1.0), only slight changes in compressive strength values were noted.

Gypsum composites are characterized by a low density (<1000kg/m3) which decreases even more while organic filler applied (850 kg/m3). The gypsum composites with shavings show lower thermal conductivity coefficients than hardened gypsum pulp.

These fillers do not pose a hazard of biological corrosion due to a low number of microorganisms preserved in hardened composites. They have also a very low natural radioactivity. It gives the possibility to apply elements made of this material in constructing buildings intended for permanent residence of people, including residential buildings.

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