Properties of Gypsum Composites with Straw Fillers

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Abstract. Results of tests of physical and mechanical properties of gypsum composites with organic fillers, in the form of cut straw are presented at the paper. The conducted tests aimed at determining the influence of gypsum mixtures composition and the manner of filler’s preparation on the quality of composites. Strength and thermal properties, natural radioactivity and susceptibility to biological corrosion have been examined. The results were interesting. Moreover using straw as a component of gypsum mixtures is particularly friendly for natural environment.

1. Introduction
This work presents the results of tests of physical and mechanical properties of gypsum composites with organic fillers, in the form of cut straw, so-called chaff. The conducted tests aimed at determining the influence of gypsum composites mixtures’ composition and the manner of filler’s preparation on the quality of composites, and in particular on their strength and thermal properties. The natural radioactivity and susceptibility to biological corrosion have also been examined. The results of these tests were positive in respect of the suitability of materials in question for the building industry. Using straw as a component of gypsum mixtures is particularly beneficial in the conditions of rural construction, because this raw material is easy accessible and often treated as waste. Thus this activity is friendly for natural environment.

2. Methodology of Tests
Due to the method of production, the poured, cast and underwater gypsum composites are differentiated. The first method, which gives greater research possibilities in respect of determining the interrelation between the properties of hardened composites and the composition and physical properties of gypsum mixtures, has been applied in the tests. From the practical point of view, this method also ensures more uniform distribution of composite filler’s particles.

The wheat straw, cut to three different lengths (10, 20 and 30 mm), in order to determine a possible influence of organic particles’ length on the mechanical properties of gypsum composites, was used as the filler. The application of elongated elements can fulfil the function of fibre reinforcement, similarly as in the case of fibre concretes.

A number of technological recipes have been designed. The straw, cut on the bookbinding cutter, was used in the quantity of 2, 3, 4, 5 and 6% in relation to the gypsum mass. While establishing the recipes, it has been assumed as purposeful to check the influence of the water-gypsum ratio on the composite properties. Three different W/G ratios were applied: 0.8, 0.9 and 1.0. The percentage of the filler was reproduced at each length of straw, repeating this cycle for each W/G ratio.

Both the non-mineralized straw and the straw after mineralization with CaCl₂ and Ca(OH)₂, were used.

The test samples of gypsum composites have been prepared according to the following scheme:
samples – beams 4 x 4 x 16 cm for partial tests; samples – 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.

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 straw 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 and calcium hydroxide 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 samples have been conducted, due to a potential hazard of biological corrosion of the composites. [1-6]

3. Discussion

The results of conducted tests are presented in Tables 1, 2 and 3. Comparing the results of the tests presented in Table 1, it can be concluded that the mineralization with CaCl₂ is not purposeful, because both the bending and compression strengths of the samples are very low. The samples with W/G ratio = 0.8 have shown the highest compression strength. It ranges from 1.0 to 1.9 MPa, and it is not possible to determine the influence of the straw particles’ length on running of this mechanical property. These results do not allow assessing the influence of filler’s quantity on the composites’ strength either. The situation is similar in the case of bending strength and apparent density. After increasing of W/G ratio to 0.9 and 1.0, the composites’ strength decreases rapidly and the apparent density lowers insignificantly. Considerably more favourable results have been obtained after examining the gypsum composites with the filler treated with calcium hydroxide. The compression strength reaches the values above 3 MPa only in several cases, but the majority of them reach the value near or above 2 MPa, and such a rapid drop of strength as previously does not occur along with the increase of W/G to 0.9 and 1.0. The bending strength runs likewise. Similarly as in the previous case, it is difficult to establish the influence of filler’s length on the increase of compression and bending strengths.

The apparent density ranges from 800 to 980 kg/m³, whereas the highest values have been obtained for the samples with W/G = 0.8.
### Table 1. Results of partial tests for the samples of gypsum composites with cut straw filler, mineralized with 5% CaCl₂ solution and 5% Ca(OH)₂ solution

| Sample no. | Quantity of filler in relation to gypsum mass [%] | Straw length [mm] | W/G | Apparent density [kg/m³] | Bending strength [MPa] | Compression strength [MPa] |
|------------|-----------------------------------------------|------------------|-----|-------------------------|------------------------|--------------------------|
| 1          | 2                                             | 10               | 0,8 | 956                     | 984                    | 1,00                     |
| 2          | 2                                             | 20               | 0,8 | 954                     | 972                    | 1,21                     |
| 3          | 2                                             | 30               | 0,8 | 964                     | 963                    | 1,26                     |
| 4          | 3                                             | 10               | 0,8 | 954                     | 968                    | 1,31                     |
| 5          | 3                                             | 20               | 0,8 | 958                     | 931                    | 1,25                     |
| 6          | 3                                             | 30               | 0,8 | 954                     | 942                    | 1,45                     |
| 7          | 4                                             | 10               | 0,8 | 950                     | 940                    | 1,38                     |
| 8          | 4                                             | 20               | 0,8 | 942                     | 929                    | 1,48                     |
| 9          | 4                                             | 30               | 0,8 | 970                     | 920                    | 1,60                     |
| 10         | 5                                             | 10               | 0,8 | 908                     | 906                    | 1,27                     |
| 11         | 5                                             | 20               | 0,8 | 894                     | 929                    | 1,39                     |
| 12         | 5                                             | 30               | 0,8 | 920                     | 910                    | 1,75                     |
| 13         | 6                                             | 10               | 0,8 | 899                     | 904                    | 1,65                     |
| 14         | 6                                             | 20               | 0,8 | 903                     | 906                    | 1,48                     |
| 15         | 6                                             | 30               | 0,8 | 908                     | 898                    | 1,99                     |
| 16         | 2                                             | 10               | 0,9 | 862                     | 903                    | 0,49                     |
| 17         | 2                                             | 20               | 0,9 | 883                     | 907                    | 0,78                     |
| 18         | 2                                             | 30               | 0,9 | 860                     | 904                    | 0,67                     |
| 19         | 3                                             | 10               | 0,9 | 842                     | 867                    | 0,54                     |
| 20         | 3                                             | 20               | 0,9 | 857                     | 872                    | 0,70                     |
| 21         | 3                                             | 30               | 0,9 | 841                     | 865                    | 0,77                     |
| 22         | 4                                             | 10               | 0,9 | 877                     | 872                    | 0,76                     |
| 23         | 4                                             | 20               | 0,9 | 868                     | 889                    | 1,05                     |
| 24         | 4                                             | 30               | 0,9 | 890                     | 872                    | 1,21                     |
| 25         | 5                                             | 10               | 0,9 | 906                     | 845                    | 0,92                     |
| 26         | 5                                             | 20               | 0,9 | 869                     | 863                    | 0,98                     |
| 27         | 5                                             | 30               | 0,9 | 881                     | 858                    | 1,17                     |
| 28         | 6                                             | 10               | 0,9 | 864                     | 872                    | 0,92                     |
| 29         | 6                                             | 20               | 0,9 | 854                     | 837                    | 1,09                     |
| 30         | 6                                             | 30               | 0,9 | 872                     | 845                    | 1,09                     |
| 31         | 2                                             | 10               | 1,0 | 775                     | 8,52                   | 0,49                     |
| 32         | 2                                             | 20               | 1,0 | 797                     | 8,94                   | 0,49                     |
| 33         | 2                                             | 30               | 1,0 | 747                     | 8,47                   | 0,49                     |
| 34         | 3                                             | 10               | 1,0 | 814                     | 8,37                   | 0,49                     |
| 35         | 3                                             | 20               | 1,0 | 832                     | 8,49                   | 0,49                     |
| 36         | 3                                             | 30               | 1,0 | 802                     | 8,38                   | 0,73                     |
| 37         | 4                                             | 10               | 1,0 | 836                     | 8,12                   | 0,75                     |
| 38         | 4                                             | 20               | 1,0 | 829                     | 8,32                   | 0,78                     |
| 39         | 4                                             | 30               | 1,0 | 802                     | 8,23                   | 0,74                     |
| 40         | 5                                             | 10               | 1,0 | 792                     | 8,00                   | 0,68                     |
| 41         | 5                                             | 20               | 1,0 | 797                     | 8,09                   | 0,49                     |
| 42         | 5                                             | 30               | 1,0 | 777                     | 8,05                   | 0,91                     |
| 43         | 6                                             | 10               | 1,0 | 778                     | 7,60                   | 0,69                     |
| 44         | 6                                             | 20               | 1,0 | 816                     | 7,90                   | 0,93                     |
| 45         | 6                                             | 30               | 1,0 | 785                     | 8,19                   | 1,4                      |
For more comprehensive assessment of the quality of gypsum composites with straw fillers, the extended tests have been conducted on 10 x 10 x 10 cm samples, for selected technological recipes. The results of these tests are presented in Tables 2 and 3, and the properties of composites with non-mineralized fillers are presented in the first of them. The results of the compression strength test are also presented in these tables, in order to obtain a more complete picture of the quality of these composites. The non-mineralized samples have not reached the minimal compression strength amounting to 3 MPa, but within the range from 2 to 2.5 MPa. These composites meet the technical conditions as for the sawdust gypsum composites only in respect of the softening coefficient. This value ranges from 0.39 to 0.48. The sample “0”, made of gypsum slurry without fillers, has been included in the table for comparison.

Table 2. Results of full tests for gypsum-concrete samples with non-mineralized filler (straw, length 20 mm)

| Sample no. | Quantity of filler in relation to gypsum mass % | W/G | Compression strength | Mass absorbability % | Softening coefficient | Thermal conductivity coefficient |
|------------|-----------------------------------------------|-----|----------------------|----------------------|----------------------|---------------------------------|
| 0*         | -                                             | 0.65| 7.6                  | 35                   | 0.36                 | 0.66                            |
| 1          | 2                                             | 0.8 | 2.5                  | 47                   | 0.44                 | 0.55                            |
| 2          | 3                                             | 0.8 | 2.4                  | 49                   | 0.39                 | 0.52                            |
| 3          | 6                                             | 0.8 | 2.1                  | 49                   | 0.48                 | 0.49                            |

* sample made of gypsum slurry without fillers

Table 3. Results of full tests for gypsum composites samples with mineralized fillers (straw, length 20 mm)

| Sample no. | Quantity of filler in relation to gypsum mass % | W/G | Compression strength [MPa] | Mass absorbability % | Softening coefficient | Thermal conductivity coefficient |
|------------|-----------------------------------------------|-----|-----------------------------|----------------------|----------------------|---------------------------------|
| 1          | 2                                             | 0.8 | CaCl₂ 3.1                  | 54                   | 0.35                 | 0.43                            |
| 2          | 3                                             | 0.8 | CaCl₂ 3.0                  | 56                   | 0.36                 | 0.38                            |
| 3          | 6                                             | 0.8 | CaCl₂ 2.2                  | 58                   | 0.39                 | 0.36                            |
| 4          | 2                                             | 0.9 | Ca(OH)₂ 2.5               | 61                   | 0.42                 | 0.38                            |
| 5          | 6                                             | 0.9 | Ca(OH)₂ 1.5               | 63                   | 0.46                 | 0.44                            |
| 6          | 3                                             | 1.0 | CaCl₂ 2.1                  | 64                   | 0.33                 | 0.51                            |
| 7          | 6                                             | 1.0 | Ca(OH)₂ 1.2               | 65                   | 0.37                 | 0.42                            |
| 8          | 6                                             | 0.8 | Ca(OH)₂ 1.3               | 66                   | 0.42                 | 0.49                            |

The gypsum composites with the filler in the form of straw mineralized with calcium hydroxide have usually the strength lower than 3 MPa and their absorbability reaches even 65%. The softening coefficient is satisfactory and ranges from 0.33 to 0.46. Mineralization with calcium chloride is not favourable, because these composites are weaker and more absorbable than the previous ones.

The gypsum composites with the mineralized filler have lower thermal conductivity coefficients than those with non-mineralized fillers.

Both the samples of filler and gypsum composites with this filler were subjected to the tests for the presence of bacterial flora. First, the pH of straw was determined and it amounted to 6.0. The reaction of the gypsum binder amounted to 8.5. After merging the gypsum binder with a filler, the gypsum composites have shown the pH = 7.3. In such conditions, close to the neutral reaction, the conditions for the development of bacterial flora may exist. Therefore, the microbiological tests have been conducted. 10 g of the examined material was prepared and poured with sterile distilled water. After 15 minutes, the reaction was measured and the sample was sown on a sterile substrate in order to carry out a quantitative assessment of individual groups of organisms. Standard, selective substrates for culturing bacteria, fungi, algae and protozoa, were applied. The results of the quantitative analysis of organisms are presented in Table 4. After 4 days of incubation the presence of algae was not
detected. As it results from the analysis of quantitative status of individual groups of microorganisms, the quantity of fungi introduced to the gypsum composite mixture along with the organic fillers decreases rapidly. As for the mesophilic bacteria, more of them were found in the gypsum composite than in the filler. However, it is difficult to determine the source of their origin, because they could get into a sample from the air. Generally, the detected organisms do not pose a hazard of biological corrosion for gypsum composites.

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

| No. | Kind of microorganisms | Incubation time [h] (temp. °C) | Straw (JTK/g) | Gypsum composite with filler (JTK/g) |
|-----|------------------------|-------------------------------|--------------|-------------------------------------|
| I   | Bacteria:              |                               |              |                                     |
| 1   | Psychrotrophic         | 72h (20°C)                    | 2000         | 3000                                |
| 2   | Mesophilic             | 24h (37°C)                    | 150          | 850                                 |
| 3   | Autotrophic            | 72h (20°C)                    | 20           | -                                   |
| I   | Fungus                 | 120h (20°C)                   | 2000         | 40                                  |
| III | Protozoa               | 96h (20°C)                    | 30           | 25                                  |

Moreover, the natural radioactivity of the samples of the gypsum slurry with the addition of cut straw was examined. The assessment of results was explicitly positive, because the sample met the requirements in the scope of allowable concentrations of radioactive elements. Radiation intensity amounted to 9.9 Bq/kg, i.e. 5.4% of MPV (maximum permissible value). [7, 8, 9]

4. Summary
The tests of gypsum composites with the filler in the form of cut straw, in amount of 2 – 6% in relation to the gypsum mass, have delivered interesting information. It appeared that the mineralization with calcium chloride is not purposeful, because the mechanical strength of composites decreases. In this respect, more favourable results were obtained after applying a mineralizer in the form of calcium hydroxide. The compression strength rarely reaches the value above 3 MPa, but in most cases it runs near or above 2 MPa, and such a rapid decrease of composites’ strength as it occurred in case of mineralization with calcium chloride is not observed along with the increase of W/G ratio to the values of 0.9 and 1.0.

There are premises (Table 1) that the length of straw particles can influence, though insignificantly, the run of bending and compression strengths. In case of bending strength, slightly better results were obtained after application of 30 mm long straw, while shorter particles of straw can have bigger influence on compression.

The gypsum composites which contain cut straw could find their application in the building industry. The availability of the filler, particularly in rural conditions, creates possibilities for prefabrication of light gypsum composites elements for the building industry. The samples of such composites show high softening coefficients. Based on the results of full tests, the technical conditions for these gypsum composites can be roughly determined. The content of the filler should not exceed 3% in relation to the gypsum mass. Mineralization with calcium hydroxide is a favourable procedure. The water-gypsum coefficient should not be higher than 0.8. When such conditions were met, the samples achieved the strength of 3 MPa, at the softening coefficient of 0.36.

The gypsum composites with straw fillers show lower thermal conductivity coefficients than hardened gypsum slurries. These fillers do not pose a hazard of biological corrosion due to a slight amount 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 the objects designed to accommodate people.
5. References
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