High Strength Phosphogypsum and Its Use as a Building Material

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Abstract. A new process (patent applied) that works equally well with both plaster of mineral gypsum and phosphogypsum for the preparation of gypsum components, UCOS, has been developed. The process consists of the following steps: humidification of plaster by fine water droplets, uni-axial compression, hydration reaction and drying. Strong hydrogen bonds develop among the crystals together with adhesion provided by confined water that accounts for nearly 70% of the adhesion forces. By reducing the plaster to water ratio to close the minimum necessary, new features are generated. An experimental house has been constructed, in which walls and ceilings have been built of gypsum and phosphogypsum. Since phosphogypsum potentially contain radioactive elements, the application of an activity concentration index to the phosphogypsum employed in the building was carried out.

Keywords: Phosphogypsum, Building Materials, Activity Concentration Index.
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HIGH STRENGTH PHOSPHOGYPSUM

Since long date, men have been preparing plaster pieces by the following process: mineral crushing ($CaSO_4.2H_2O$) followed by a thermal treatment about 160ºC and a controlled milling. This thermal treatment changes the dihydrate (DH) into the hemihydrate (HH), according to the reaction

$$CaSO_4.2H_2O + \text{heat} \rightarrow CaSO_4.\frac{1}{2}H_2O + H_2O$$

Water is added to the hemihydrate in such a quantity that results in a low viscosity suspension, which, after poured on a mold, is able to exactly replicate objects. In order to reach an appropriate suspension viscosity, the mass ratio of water to the hemihydrate (w/HH) must range from 1.2 to 0.8. However, according to the reaction stoichiometry, the ratio w/HH=0.186 should be sufficient for the fully conversion of HH into DH.

In this way, the relative excess of water is responsible for the characteristics usually associated with the plaster: low mechanical strength and high susceptibility to moist. This means that the solution to obtain plaster pieces with higher mechanical strength lies on the addition of the minimum quantity of water as well as on the application of pressure to bring the DH crystallites into close contact (being the later stage of drying important to maximize the mechanical performance). This summarizes the method we devised and called UCOS, which patent was already filed in Brazil and at PCT. Hereby, gypsum plates with high mechanical strength - far superior to the other commercial gypsum-based products such as the drywall panels, for instance, are shown in Table 1. Figure 1 shows the gypsum plates already obtained.

TABLE 1. Composition and mechanical characteristics of composite materials.

Material obtained by UCOS	**Water/HH**	**ρ (g/cm^3)**	**Compressive strength (MPa)**	**Bending strength (MPa)**
Plasterβ (Commercial)	0.20	1.8	65.0	22.0
Phosphogypsum	0.25	1.8	64.5	28.6
50% Plasterβ + 50% Phosphogypsum	0.25	1.8	63.0	23.1
90% Plasterβ + 10% Cellulose	0.25	1.5	55.0	30.0
Drywall material	1.00	0.8	4.2	6.6

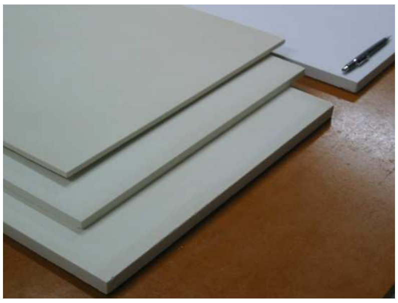

FIGURE 1. NEWGYPSUM plates

The attractive forces among the DH crystallites are responsible for the mechanical strength of gypsum-based material. These forces rise with reducing the gap among those crystallites, i.e. by packing the moist HH before hydration reaction occurs. This packing can be undertaken with the help of an isostatic, uniaxial or biaxial pressing.

THE EXPERIMENTAL HOUSE

The social housing deficit is at the basis of social-economic triangle for developing our country. The use of a by-product like phosphogypsum, abundant and with low price, along with the preservation of natural gypsum resources, could have a positive environmental impact. Challenging the need for build more with less impact on natural resources, Inovamat is devising new products and building systems for this kind of dwellings. Furthermore, the company has built an experimental house (Figure 2) to demonstrate the great potential of using this new material, as its walls and ceilings have been built of gypsum and phosphogypsum.

FIGURE 2. Frontal view of the experimental house

In the experimental house, steel frames were screwed into the radier basement; next, the roofing was fixed on the steel frame. This kind of roof weighs only 1/7 in addition to the half of cost of a conventional one, often made of wood structure and heavy clay tiles. The greatest innovation in this house was the way it was lined: by fixing NEWGYPSUM panels (120x60cm^2) in the steel frame. The fixing fulfills the requirement to prevent the crack propagation resulting from differential thermal dilation of the materials.

The advantages of the NEWGYPSUM panels in comparison to the drywall are as follows: better performance on moist environment, higher toughness, and mechanical strength much superior, even when compared to brick masonry. Unlikely the raw material the bricks are made of, gypsum from panels can be completely recycled according to our UCOS method. The panels in the experimental house are sheathed with blankets in between, as well as between the roof and the ceiling, in order to improve thermal and acoustic comfort. It still has the option of making use of tubes between the roof and the ceiling to act as a collector of solar energy for the heating of water to the bathrooms.

RADIOLOGICAL CONCERNS

Phosphogypsum can contain radioactive elements which demands precaution in its use as a building material. In order to comply with regulatory standards, the concentration of radioactive elements in the plates can be reduced as needed, by making composites materials by diluting phosphogypsum with other, less radioactive materials, such as the proper mineral gypsum as cellulose as well, with the same mechanical performance as follows the table above

The limit adopted, for the exemption and clearance of materials for general purposes, in Safety Report Series 44[1] is 1 Bq/g for natural radionuclides comprising the decay series of U and Th and 10 Bq/g for K-40. Previous studies[2] have shown evidences that the radioactive level of most of the Brazilian phosphogypsum is below 1 Bq/g. In order to carry out radiological studies in situ, a room in the experimental house was designed for the evaluation of the levels of radioactivity and emanation of the Radon gas (Rn) from different sources of phosphogypsum. This room was completely lined (walls and ceiling) with phosphogypsum plates obtained by the UCOS method.

Assessment of Activity Concentration Index

Using of building materials containing naturally occurring radionuclides may cause an increment to the radiation doses to which public individuals are exposed, caused by the gamma emissions from each radionuclide itself or from its progeny.

For practical monitoring purposes, investigation levels can be presented in the form of an activity concentration index I defined as[3]

$$I = \frac{C_{Ra}}{300\,\text{Bq kg}^{-1}} + \frac{C_{Th}}{200\,\text{Bq kg}^{-1}} + \frac{C_{K}}{3000\,\text{Bq kg}^{-1}} \qquad (1)$$

The concentrations of these radionuclides were measured in samples of phosphogypsum used in the construction of the house. Applying directly this expression to the mean values of the concentrations, one obtains $I = 1.8$. This value surpasses the $I \leq 1$ criterion for bulk usage (that is, 20cm-thick walls), but does comply with the $I \leq 6$ criterion for superficial or restricted use. In our case we should take into account the second criterion, since in the experimental house the material is used in the form of thin phosphogypsum plates, with thicknesses of 1.5 cm for the walls and 1.0 cm for the ceiling. Therefore, it is expected that the dose increment will remain far below 1 mSv per year. In order to confirm that the radiological hazards are negligible, the determination of indoor radon levels[4] at the experimental house, as well as the application of a previously developed[5] gamma-ray transport theoretical model to forecast external radiation doses, will be applied.

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