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Study of modified gypsum binder

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HIGHLIGHTS

- Kinds of additive have influence on the hydration process and the gypsum structure.
- The additive content enhances the compressive strength and water resistance of gypsum.
- With additives a denser finecrystalline structure is formed.
- Taurit and silica introduced together increase the durability characteristics.

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ABSTRACT

Nowadays the addition of small amounts of chemical additives allows developing new types of binding materials. The effect of microadditives on the performance of β-hemihydrate gypsum has been studied. 1% content of complex additive contributes to enhancement of compressive strength and water resistance in modified samples as compared to reference one. These studies showed that additives accelerate the rate of hydration and lead to the formation of a dense and well-compacted texture of crystals, thereby imparting, to gypsum matrix, higher strength and better water resistance than the reference materials.

1. Introduction

The range of application of gypsum building materials and products is significantly inferior to the similar materials based on cement because of their low strength and water resistance. Basically, gypsum materials and products are used indoor in dry and normal humidity conditions.

One of the most effective ways to increase gypsum's water resistance and strength is using different additives. Researches are carried out in several directions, among which is the investigation of the processes of structure formation under the influence of various factors, plasticizers of different actions, additives etc [1–3].

The aim of the investigation is to establish the influence of additives of modifiers on the structure and properties of gypsum binders, studying the process of structure formation of gypsum hydration systems.

The properties of materials depend on their compositions and structures that are interconnected and in balance. Creation of materials with special properties should be based on the main knowledge of the material's structure: laws ruling its formation and regulation of its properties influencing the structure as part of the process. A key element of the triangle structure-property-technology is the concept of structure that is closely related not only to important properties of material but also to the conditions of technological processes.

That is impossible without solving the problem of theoretical generalization and further study of the complex processes that lead to the formation of structure, to physic and mechanical properties of binding materials and their connection with the composition of the starting materials. Most of the works in the field of gypsum binders were devoted to the study of processes from a physical-chemical mechanics point of view [2,4–8]. However, these studies do not reveal the relationship between the structure of the crystal lattice of gypsum binders and their reactivity. In other articles, influence of pH, temperature and additives concentration on crystallographic variety and structure

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of gypsum were reported without mechanical properties observation [9–12].

The action of modifiers appears through the processes in the interfaces of solid, liquid and gaseous phases. Adsorption layers of modifiers on the surface of the solid particles have different important tasks: influence on rate of crystal growing, its morphology and crystallographic varieties.

One of the main difficulties is that the modified systems are multicomponent. Then, the individual and joint influences of components should be taken into account, but are difficult to represent in an analytical form.

The results of researches show differences that are related to the concentration of additives and to properties modifications. The content of modifiers is significantly different in many works (within 0.025–0.15%). The reported rates of strength increase are from 20 to 50%. Differences between the results and absence of clear dependences can be explained by the following factors: kind of additive, synthesis parameters, structural and morphological features, method of addition into binder and degree of dispersion of modifiers, on one hand, and chemical composition of the surface of the binder, on the other hand [13].

Some of the most common hypotheses which explain the change in the properties of gypsum binder with micro- and nanoadditives can be enumerated [14–17]:

- nanoparticles change the surface charge and then affect electroconduction properties;
- rheological properties are modified;
- nanostructures act as crystallization centers;
- high density of contact points increases the traction between particles:
- nanoparticles introduction is connected with active surface area and the surface energy excess that influences the crystal morphology.

The algorithm to solve the problem of rational modification can be represented as follows:

- study of wide range of modifiers to identify positive impact;
- definition of technological methods for addition of small quantity of modifiers;
- study of the structural and morphological changes in the hydration products;
- definition of features of structure formation with different modifiers.

Structures of gypsum binder formed with various additives were investigated in this research work.

2. Experimental section

2.1. Instrumentation

The phase compositions of the resulting products were determined by X-ray powder diffraction: patterns were recorded at room temperature with Cu Kα radiation on a PANalytical X'pert Pro diffractometer equipped with the X'celerator detector in the 2θ range from 5° to 70° (step 0.033°, time/step 50 s). To prepare the samples the powder was sieved with 63 μm mesh. The phase identifications and Rietveld refinements were performed with X'Pert HighScore Plus software. In our samples, the diagrams' analyses led to the identification of several phases which are gathered with their structural data in Table 1. These structural data were downloaded as files in the format ∗.cif and used to perform Rietveld refinement and phase quantification.

Thermal analyses were carried out by using Q600 SDT TA Instruments equipment. The temperature was raised from RT up to 800 °C at a heating rate of 10 °C/min under dry air flow (100 mL·min^{-1}) with α-Al_2O_3 as reference.

Changes in the microstructure of composites were observed by SEM. SEM images were carried out on a JEOL, JSM 6510 LV microscope working with W filament and an accelerating voltage of 15 kV.

2.2. Materials

Composites based on gypsum binder have been investigated in this research. The basic component of composite is gypsum plaster G-4-H-IIc, which was made in "Kamenetsk-Podilsk" (Ukraine).

The X-ray characterization shows that gypsum plaster G-4 contains 66.5% of $CaSO_4{\cdot}0.5H_2O$, 17.0% of $CaSO_4$, 12.0% of $CaSO_4{\cdot}2H_2O$, traces of SiO_2 and $CaCO_3$ (Fig. 1, Table 1).

Taurit TS-D and white druss (silica) were used as additives to gypsum composite.

The density of Taurit TS-D is 493 kg/m^3. Taurit brand "TC-D" (Kazakhstan) is used as a stable color pigment in the manufacture of different kinds of building materials. Taurit brand "TC-D" has following features: increases frost resistance; shine and volume-lasting color, from gray to dark-gray color; accelerates time of setting; increases the water resistance of products; gives an excellent surface appearance; increases durability, initial and final strength of binder [18]. The corresponding X-ray diffraction diagram and its identification are given in Fig. 2.

White druss (silica) is a commercial product (Ukraine). It contains SiO_2 and its particles have average size 50–77 nm. Silica is used as a fine-grained filler for composite material. According to results of X-ray diffractometry, silica is amorphous.

2.3. Preparation of test samples

Different compositions of samples were prepared in order to investigate the effect of additives.

At first, the main properties of gypsum without additive were investigated according to the *National Standard of Ukraine DSTU Б B.2.7-82: 2010 Building materials. Gypsum binders*. Homogeneous paste of gypsum was prepared manually by admixing hemihydrate gypsum G-4 with water. The quantity of water required to produce paste of standard consistency was 50 wt% and was determined in previous tests for this kind of gypsum plaster. The measured compressive strength of samples is 4.2 MPa.

For samples with additives, Taurit and silica were added to hemihydrate gypsum plaster G-4 and thoroughly mixed, after that, water was added to get paste of standard consistency. Mixed compositions of gypsum plaster with different additives are presented in the Table 2.

Immediately after mixing with water, the samples were casted into metal molds of size 40 × 40 × 160 mm. After 2 h, the samples were unmolded and tested for compressive and flexural strength. Six samples from different compositions were used for each test.

Water resistance coefficient was defined as a ratio of compressive strength in water-saturated state to compressive strength in dry state.

3. Results and discussion

3.1. Preparation and physical properties measurements

At the first stage of the research, gypsum paste of normal consistency and standard specimens were tested. The following parameters were investigated: time of setting of gypsum paste (τ); compressive (R_c) and flexural strength (R_f) of gypsum specimens; water resistance coefficient (k_w).

In order to investigate the influence of additives on gypsum binder, different compositions of samples were prepared by adding Taurit and silica, in the weight range from 0.5 to 1.0%, to gypsum plaster. As the reference material, hemihydrate gypsum G-4 without additive was used. The optimal concentrations of additives were found: Taurit – 1.0%, silica – 1.0%, complex additive: Taurit 0.5% and silica 0.5%, which were added to gypsum hemihydrate over 100%.

3.2. Hydration process

Hydration of hemihydrate gypsum is an exothermic reaction and occurs as:

$$CaSO_4 \cdot 0.5H_2O + 1.5H_2O \rightarrow CaSO_4 \cdot 2H_2O + Q$$

In order to compare the hydration activity of gypsum binder with different additives, the temperature variation of the paste (water-gypsum ratio is 0.5) was measured as a function of time.

The study of the temperature of the hydration process showed that addition of modifiers to gypsum binder holds to an intensification of the hydration process. The curve of temperature's increase