Effective building mixtures based on hemihydrate plaster and highly dispersed mineral fillers

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Abstract. The work was aimed at developing a gypsum dry construction mixture with highly dispersed fillers based on industrial waste for interior decoration. The problem of creating effective gypsum materials was solved by improving the structural, physical and mechanical properties of gypsum stone by modifying it with highly dispersed fillers. The effect was achieved by creating a multicomponent composition based on hemihydrate plaster. The proposed work is aimed at developing a gypsum dry construction mixture with highly dispersed fillers for interior decoration of buildings. Dry construction mixes based on gypsum binder are one of the most relevant materials on the building supplies market. They meet the most important aspects from the standpoint of efficiency and safety - environmental, fire and others. However, the problem of ensuring high performance properties requires a solution. In this work, the problem is solved by improving the structural, physical and mechanical properties of gypsum stone by modifying it with highly dispersed fillers. The effect was achieved by creating a multicomponent composition based on plaster. Additionally, the problem of environmental protection is being solved, since secondary products were used as fillers - waste from the production of basalt products and thermal power plants. They differ in the required grain and chemical composition. Acid ash was used. Basalt and acid ash particles have a mechanical effect on the structure of the gypsum stone and influence the processes of structure formation of the gypsum stone. They change the morphology of gypsum crystals. This improves the mechanical strength, the average density of the modified gypsum stone and other physical and mechanical characteristics.

1. Introduction

Modern approaches to the design of dry building mixtures are based on ensuring their environmental safety throughout the entire life cycle from the extraction of raw materials to the disposal of a worn-out product. Energy intensity of the production of building mixtures based on mineral binders is also of great importance today. It is gypsum binders and dry building mixtures that fully meet such approaches. For gypsum-based mixtures, these advantages are paramount. Since gypsum binder is successfully used for interior decoration of civil and residential buildings. It is gypsum and dry building mixtures based on it that provide a favorable microclimate, do not emit toxic gases, have high economic efficiency and low energy consumption in production [1-4]. The production of calcium sulfate hemihydrate is the
least energy intensive. Compared to Portland cement. Its production will require four times as much energy. An additional advantage of calcium sulfate hemihydrate is the absence of harmful emissions into the atmosphere during its manufacture. Thus, hemihydrate plaster is the most promising binder for use in dry building mixtures. Thus, hemihydrate plaster is the most promising binder for use in dry building mixtures. However, a number of factors prevent the widespread use of gypsum mixtures. The low strength of a stone based on hemihydrate plaster leads to the need to use a gypsum binder with a higher strength. Or it is necessary to use a Portland cement additive. This means that energy efficiency decreases and the cost increases. Consequently, there is a need to design compositions of gypsum composite materials and products with improved technical properties without increasing their cost. This will help expand the scope of their application in construction [1, 5]. The need to obtain effective dry gypsum building mixtures with improved structural and mechanical properties determines the solution to the problem by modifying them with industrial waste. Particular attention is drawn to highly dispersed mineral waste, such as ash or dust removal. It should be noted that the use of waste also makes it possible to solve the environmental problems of many regions, where a large amount of waste accumulates, which is not used in industry and occupies significant areas for their storage [6, 7]. This also applies to industrial dust waste. The researchers note that the design of gypsum dry mortars does not focus solely on the use of mineral fillers. Chemical additives are widely used today. Their introduction into the composition of building mixtures makes it possible to form properties in a targeted manner, taking into account their purpose. Therefore, it is possible to ensure their high quality. In addition, it is possible to reduce the consumption of expensive substances, which means - to reduce the cost of the final product. This may affect the efficiency of production of modified mixtures [7-15]. The effect of chemical additives on the properties of dry building mixtures is formed based on many factors: the amount of additives introduced, their compatibility with other components of the mixtures, the method used for introducing the additive, mixing the mixture, dosing accuracy, technological modes and many other factors [8]. Thus, obtaining an effective building mixture can be considered as a complex multicriteria task. So, for example, it is possible to synthesize a gypsum structure with certain characteristics, or to provide the necessary setting times, high frost resistance, corrosion properties, etc. Chemical additives can also change the rheology of the mixture - to reduce the water content as a mixing agent and at the same time provide an increase in strength and a decrease in density. The high efficiency of this group of additives allowed them to find wide application in the production of dry building mixtures [10-13]. Researchers use various chemical additives and complexes of such additives to improve the rheological characteristics of gypsum mixtures, but this can adversely affect the crystallization processes of gypsum dihydrate. On the one hand, the adsorption of chemical additive molecules on binder grains and gypsum crystals after hydration provides the formation of short prismatic crystals of calcium sulfate dihydrate. On the other hand, the formation of a fine-crystalline structure due to the creation of a large number of crystallization centers [9] may affect other performance characteristics. The additive substance is adsorbed on the surface of the nucleating crystals, slows down their growth, which leads to a change in the shape and size of the crystals, and, consequently, to a change in the deformative and strength properties. Thus, when developing an effective dry building mixture, it is necessary to ensure the synthesis of a gypsum composition, taking into account its purpose and requirements for safety, environmental friendliness, cost, reliability and durability.
2. Materials and methods
When carrying out the research, hemihydrate of calcium sulfate, a gypsum binder made in Samara, was used. The original gypsum stone (figure 1) was characterized by a rather low strength - no more than 4 MPa. The basalt filler (figure 2) was a waste product from the basalt production of the Tver region.

To study the physical and mechanical properties of gypsum composites, raw mixtures were prepared by mixing them with a hand mixer. The mixture of gypsum, additives was mixed dry, then the dry homogeneous composition of the building mixture was mixed with distilled water until normal density was reached. Sample cubes 20x20x20 (mm) were made from the prepared mixture.

To determine the normal density of the gypsum dough, a clean container was filled with the required amount of clean water, then a weighed portion of a dry mixture of a pure gypsum binder or a binder with additives was poured into the water. The dough was mixed with a hand mixer until smooth. Then the resulting composition was examined using a Suttard viscometer.

The characteristics (compressive strength and average density) of the resulting composite gypsum stone were determined by calculation and experimental methods. For the manufacture of samples, a sample of gypsum binder was weighed on a laboratory balance. Then it was poured into a container with mixing water for 20 s. The dough was mixed with water for 60 seconds by hand until a homogeneous dough was obtained. After 15 minutes after the end of setting, the samples were removed from the mold, marked and stored in a test room under dry conditions. For testing on the press, the sample was installed on the press supports so that the horizontal edges were in a vertical position.

3. Results
The results of studies of the effect of adding basalt dust on the normal density of gypsum dough are shown in figure 3.
Studies of the effect of basalt additives on the properties of a gypsum mixture have shown that basalt contributes to an increase in the W / S ratio. With an increase in the content of basalt powder, the water-need of the gypsum mixture also increases.

Fast setting of gypsum dough is a positive property of raw mixes. However, in some cases, fast setting is undesirable. Therefore, the effect of the addition of pulverized waste from the production of basalt fibers on the setting time of the gypsum binder was studied. It was found that the introduction of a basalt additive leads to an acceleration of the hardening process (figure 4). With an increase in the waste content from 0 to 12 %, the setting time is reduced by 2 minutes in comparison with the control formulations without additive. Both at the beginning and at the end of the setting. Moreover, the nature of reducing the setting time is monotonous.

In order to study the influence of the content of basalt waste on the strength characteristics of the composite gypsum mixture, the method of a mathematical planned experiment was used (figure 5). The following factors were taken as investigated factors: X₁ - percentage of basalt from the mass of gypsum binder, X₂ - water-solid ratio (W / S). Based on the obtained results of statistical processing, mathematical models were built. The regression equation (equation 1) is:

\[
Y(R) = f(x_1,x_2) = 9.90216 - 0.27555 \cdot x_1 - 0.14028 \cdot x_2 - 0.79838 \cdot x_1^2 + \]

(1)
Studies have established that the optimal content of pulverized waste from the production of basalt fibers in the mineral composition of gypsum dry construction mixture is 10% of the mass of gypsum binder, and the optimal water-solid ratio for this composition in terms of strength is 0.76.

At the next stage, the properties of a composite mixture based on gypsum with lime and fuel ash additives were investigated. The work also used the method of mathematical planned experiment. The amount of pulverized waste from the production of basalt fibers was taken constant – 10%. The amount of mixing water was taken to correspond to the normal density for each of the solutions.

The studied factors were taken as follows: $X_1$ - lime content (%) of the mass of gypsum binder, $X_2$ - ash content (%) of the mass of gypsum binder.

Based on the obtained results of statistical processing, a model was built for the dependence of strength on the content of ash and lime additives in the composition of the gypsum composite mixture. The resulting regression equation is presented below (equation 2):

$$Y(R) = f(x_1, x_2) = 8.95286 + 0.34068 \cdot x_1 + 0.02672 \cdot x_2 + 0.33953 \cdot x_1^2 + 0.495 \cdot x_2^2 - 0.62047 \cdot x_1 \cdot x_2;$$

The studies have shown the effectiveness of using fuel ash as a filler in composite mixtures based on calcium sulfate hemihydrate. An increase in the content of fuel ash in the dry construction mixture leads to an increase in the strength of the gypsum stone (figure 6). The interaction of highly dispersed particles of fuel ash in combination with basalt powder creates the most "advantageous" packaging in the mixture. The maximum strength of gypsum stone with a complex of mineral fillers is ensured when additionally added as a component of building lime. It is shown that with a lime content of 8 to 10% in a dry construction mixture with mineral fillers, gypsum stone achieves high strength and density.

Figure 5. Influence of basalt content on the strength of gypsum stone.
The study of the microstructure of the composite gypsum stone confirms the presence of multidirectional crystalline hydrates and a sufficiently large volume of the amorphous phase in the compacted gypsum stone (figure 7).

4. Summary
Particles of basalt and ash additives not only have a mechanical effect on the structure of gypsum stone, but also affect the processes of structure formation of gypsum stone, the morphology of crystals. They act as crystallization centers. It is also possible that they are involved in chemical processes. They are able to ensure the formation of a denser structure of gypsum stone in comparison with the original composition.

Thus, studies have confirmed the possibility of effective use of highly dispersed mineral additives based on industrial waste for the design of compositions of composite gypsum building mixtures. Such mixtures can be used for indoor work.
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