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Gypsum Composition with a Complex Based on Industrial Waste

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Basalt fiber can serve as a substitute for synthetic fiber in gypsum-reinforced materials. Similar installation materials have been used in the Green Installation Programme. Other types of fibre, including basalt dust, that have not previously been considered are also attracting much attention. It forms during dry dust removal and is an available waste from the production of basalt materials. In addition to industrial dust wastes, it is proposed to use recycled bottom ash as a dispersed filler as an additional component. During its processing, coarse fractions were removed from the ash and the content of the organic part was reduced. The purpose of this study is to explore the possibilities of an organomineral complex of additives based on basalt dust, recycled bottom fuel ash and a hyperplasticizer Melflux 2641F to improve the properties of gypsum materials. Varying the components of the organomineral complex causes a change in the properties of the resulting composition: increasing the density and compression and rupture strength, reducing water absorption. An increase in the physical and mechanical characteristics of the gypsum composite with the introduction of basalt dust and bottom ash is associated with obtaining a denser particle due to an optimally selected granulometric structure and obtaining effective gypsum composites with an optimized internal structure. The microscopic structure of the modified gypsum composite with an organomineral complex of additives was established using scanning electron microscopy (SEM). The organomineral complex changed the structure of the gypsum stone and energizing the formation of intergrowth contacts with each other.

1. Introduction

More than 7 % of anthropogenic carbon dioxide emissions in the world are due to the cement industry, due to the consumption of large amounts of resources and energy in the production of clinker (Rolfe et al., 2018). Half of the emissions are due to chemical processes during its production (Pedraza et al., 2020), and a half - from the combustion of fossil fuels. The developments by scientists are aimed at solving the problem of reducing carbon dioxide emissions by reducing the cement content in the design (Shanks et al., 2019) and in the production of reinforced concrete products (Mubashir et al., 2021), and by completely replacing them in favor of other types of binders (Pérez-García et al., 2020).

One of the most effective ways to reduce carbon dioxide emissions is to replace cement with alternative binders that do not require high temperatures during production. Binders or fillers that exclude heat treatment (waste from other industries, slags, ash) are of practical interest. The use of gypsum binder is still limited due to low strength characteristics (Anikanova et al., 2020) and lack of resistance in humid conditions). Even taking into account the low energy intensity of its production, which requires 5 times less energy than the production of Portland cement (Pérez-García et al., 2020). Deposits of gypsum stone are very widespread, its extraction is technologically developed (Buryanov et al., 2021), and the resulting binder has a number of advantages (Bouzit et al., 2019) it does not shrink during hardening, has fire resistance, and it is hygienic.

Modification of a gypsum binder and its use as a component of organo-mineral compositions can significantly expand the scope of its application (Pudovkin, 2018). The design of the optimal packing of the particles of the gypsum composition, as well as the introduction of additives (Khozin et al., 2019), allows controlling the resulting characteristics, thereby providing the necessary strength and water resistance. The introduction of

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mineral additives into the composition of gypsum compositions (Khezhev et al., 2020) is economically feasible. They make it possible to achieve an increase in strength and a decrease in water absorption by influencing the crystallization rate (in this case, the additive plays the role of a seed, being a ready center of crystallization of the main structure-forming phase) or by optimizing the structure (Doleželová et al., 2021). Waste and local raw materials are also popularly used as fillers (Asamatdinov et al., 2021). The nature and dispersion of the fillers (Long et al., 2017) and the pH value are of great importance (Klimenko, 2020). The introduction of basalt fibers or their production waste contributes to an increase in the operational characteristics of the gypsum material (Petropavlovskaya et al., 2018).

The combined use of mineral fiber, microdispersed filler, and plasticizer additives for gypsum modification can lead to a synergistic effect. The granulometric composition of the mineral complex of additives (recycled bottom ash and industrial dust) can create the necessary structure of the material with a given packing of grains. Removal of the largest fractions during the processing of bottom ash opens up the possibility of using it as a highly dispersed component of building composites. The dense structure of the reinforced gypsum stone can provide an increase in the operational properties of the material, shield the effects of water, and reduce creep. The chemical composition of processed ash and dust can affect the pH and the structure formation process in general. The use of a hyperplasticizer enhances the effect of mineral components and improves manufacturability when working with mixtures. The introduction of bottom fuel ash and the replacement of basalt fiber in reinforced gypsum materials with dust from basalt production can increase economic efficiency. The purpose of this study is to study the potential of an organomineral complex of additives based on basalt dust, recycled bottom fuel ash and the Melflux 2641F hyperplasticizer to improve the properties of gypsum materials. The correct concentration of the plasticizer improves the technical and economic characteristics of the material (Saktiesvaran and Sofia, 2018). Reducing water demand increases compressive strength and density (Dolak et al., 2016). The use of plasticizers based on polycarboxylates increases the manufacturability of working mixtures: workability, thixotropy, and pot life of the mixture (Utegenova et al., 2021). The aim of the study was to establish the possibility of using a highly dispersed part of fuel ash in combination with technogenic dispersed basalt powder as a partial replacement for a gypsum binder. Basalt powder and fuel ash as industrial waste can be used as fillers in the composition of the organo-mineral complex to increase the operational properties of the gypsum binder or to impart special properties to the composition.

2. Materials and methods

For the synthesis of the organomineral complex and the modification of gypsum stone, a dispersed mineral technogenic basalt additive in the form of industrial dust was used as microfiber. According to the results of previous studies, its content was assumed to be constant at –10 %. In addition, processed bottom fuel ash was introduced into the complex (Figure 1). The processing of ash waste made it possible to significantly change the material and grain composition of the ash additive.

Figure 1: Ash waste

Porous large particles with a high organic content could contribute to an increase in the water demand of the complex and adversely affect the mechanical and physical properties of the organomineral complex. To improve the rheological properties, Melflux 2641F hyperplasticizer was added to the modifying complex. In this work, a gypsum binder was used to study the effectiveness of the organomineral complex. Its compressive strength at the age of two hours was 5 MPa. Investigations of the properties of gypsum stone with the addition of an organic-mineral complex were carried out on standard sample cubes.

The size of the cubes was 20x20x20 mm. The gypsum stone tests were carried out in accordance with the EN standard requirements. Plaster samples were hardened at normal temperature. The compressive strength was calculated from the results of testing the samples on a hydraulic press. The average density was determined on the samples in a dry state. The samples were dried until a constant weight was reached. The structural features of gypsum crystals and compositions were evaluated by electron microscopy. The features of crystals in the structure of the modified gypsum stone were assessed by the method of electron microscopy. We used a JEOL JSM-6610LV scanning electron microscope operating in the modes of secondary and reflected electrons at an accelerating voltage. The secondary electron mode (SEI) was used to determine the topography of the samples.

3. Results and discussion

At the first stage, the effect of the addition of an ash filler on the ultimate compressive strength of a stone was investigated (Figure 2). Content of the ash was taken in an amount of 7 %. The content of the additive was optimized according to technical parameters and the economy of the gypsum binder. In further studies, the optimal content of the fuel ash additive was taken to be constant.

At the second stage, the influence of the hyperplasticizer in the composition of the organomineral complex on the compressive strength and average density of the gypsum composition was investigated. The compositions of the gypsum compositions are presented in Table 1. During the experiment, the content of the Melflux hyperplasticizer additive varied from 1.4 to 1.7 % in 0.1 % increments.

The results of studies of the dependence of the mechanical and physical properties of the modified gypsum stone on the Melflux additive are shown in Figure. 3.

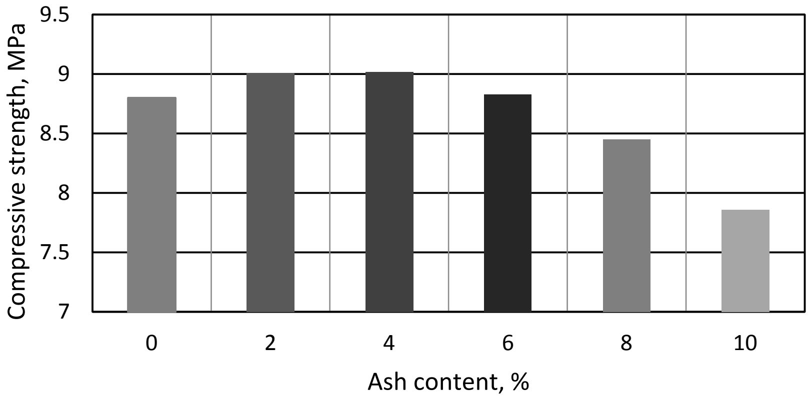


Figure 2: Influence of the amount of ash content on the compressive strength of the modified stone

Table 1: Compositions of gypsum compositions

Composition №	Gypsum, g	Waste, g	Ash, g	Melflux, g
1	100	10	7	1,64
2				1,75
3				1,90
4				2,00

The greatest value of the compressive strength of gypsum stone is achieved with an additive content of 1.5 %. Strength increases on average by 40% and reaches a value of 31.63 MPa. A further increase in the content of the Melflux hyperplasticizer additive from 1.5 to 1.7 % leads to a decrease in strength by more than 50 %. The average density of gypsum stone with an organomineral complex reaches a maximum value of 2,038 kg / m^3 with a 1.6 % Melflux hyperplasticizer additive The electrosteric effect is most pronounced in a modified composition based on a gypsum binder in the range of 1.5-1.6 %. The increased content of hyperplasticizer (over 1.5 %) negatively affects the process of hydration of the gypsum stone and its strength in the future.

The Melflux hyperplasticizer as part of an organomineral complex affects several characteristics of the mixture and gypsum stone at once - water demand, mixture rheology, strength, density and other properties of gypsum stone. The composition of the multicomponent complex enhances the effects of the influence of each of them separately. In a dispersed system, in the presence of an optimal amount of hyperplasticizer, conditions are created for the appearance of cohesion. It is provided at the beginning of the process by interparticle forces and then by bonds of a crystallochemical nature. The optimal water content corresponds to

the best conditions for the formation of the gypsum stone structure. The particle size distribution of the dispersed system provides a dense packing of particles in its composition. The early structure of the disperse system self-regulates in the direction of the gypsum particles convergence of gypsum particles to the critical distances at which connectivity is achieved, "constrained conditions" are created for the hydration, hardening and structure formation of the modified gypsum stone. A decrease in water demand during the modification with an organomineral complex causes an increase in the density of the gypsum structure.
A decrease in water demand during modification with an organomineral complex causes an increase in the density of the gypsum structure. This is facilitated by the synergistic effect of the use of ash additive and hyperplasticizer. The shape of the highly dispersed grains of the processed ash is close to spherical, which is reflected in the water-reducing effect of the mixture. The granulometric composition of the mineral composition provides a dense packing of particles in its composition.

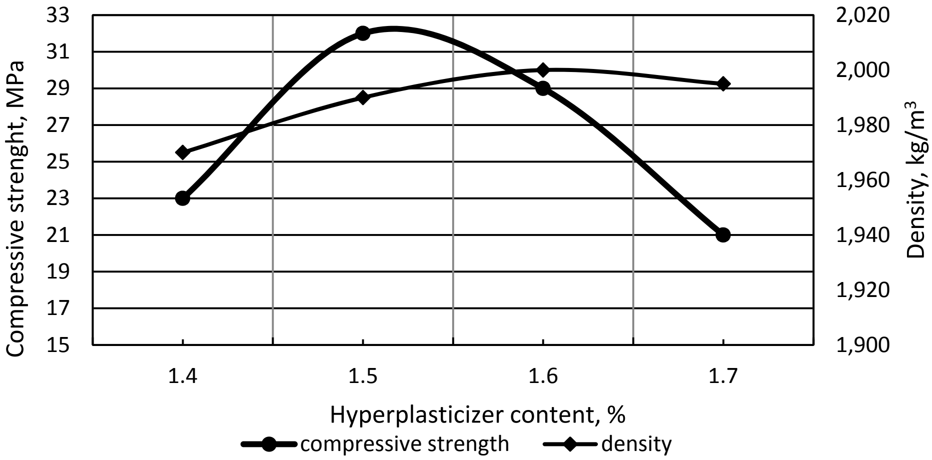
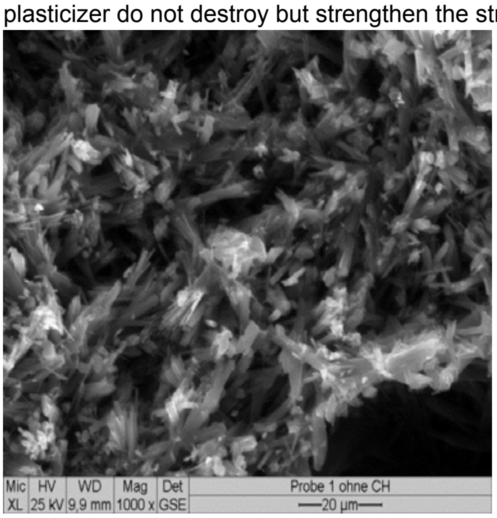


Figure 3: Influence of the amount of hyperplasticizer content on the compressive strength and density of the modified gypsum stone

This is confirmed by microstructural analysis of the gypsum stone. In a joint examination of Figures 4 and 5, a comparison was made of the sizes of crystals of a gypsum stone without an organomineral complex (Figure 4) and a modified gypsum stone (Figure 5). These photographs represent the most characteristic microstructures. In the presence of a complex of additives, a denser and more structured system of gypsum stone forms (Figure 4, 5). A change in the habit of gypsum crystals is observed. Crystals of modified gypsum stone have the shape of rectangular prisms with maximum dimensions in height and thickness: 2.4 and 1.44 µm. The products of the interaction of aluminosilicate components with the gypsum phase in the presence of a plasticizer do not destroy but strengthen the structure of the stone.



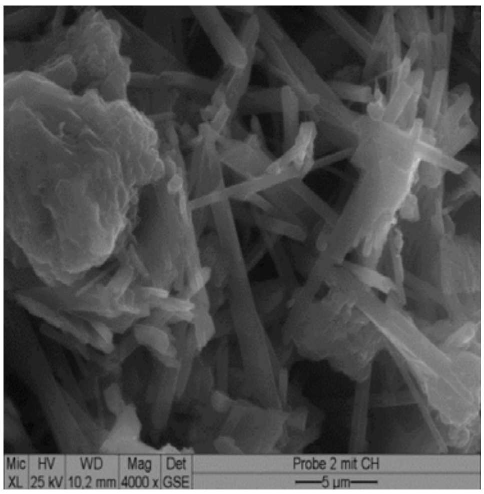


Figure 4: Microstructure of gypsum stone without mineral additives and plasticizer

The data obtained are consistent with the previously obtained dependences (Petropavlovskaya et al., 2018) and the studies of other authors (Khozin et al., 2019). The increase in the percentage of plasticizer in this composition in comparison with pure gypsum is due to an increase in dispersion and the effect of the nature of the surface of the mineral additives introduced.

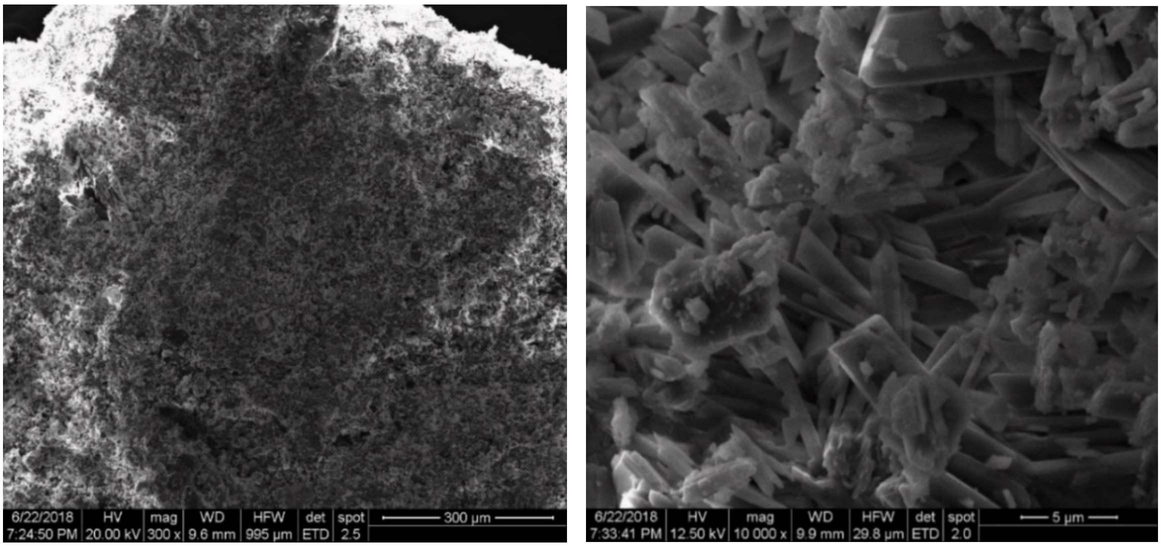


Figure 5: Microstructure of gypsum stone with a complex of additives

4. Conclusions

The results confirm the possibility of using gypsum compositions based on the technogenic waste of basalt powder and fuel ash in combination with Melflux hyperplasticizer. The introduction of an organomineral complex improves the properties of the modified gypsum stone: its density and strength increase. The change in properties is associated with a synergistic effect due to the optimally selected particle size distribution and plasticization of the mixture. The optimal water content corresponds to the best conditions for the formation of the gypsum stone structure. Self-regulation of the structure takes place - the compaction and the creation of "cramped" conditions. The content of the aluminate and silicate phases of ash in the sulfated dispersion phase determines the high-performance properties of the modified stone. The optimum content of the Melflux hyperplasticizer additive is 1.5 %, ash 7 %, basalt additive 10 %. Research in this direction will be continued. The use of fuel ash and artificial basalt powder in the production of building materials increases the economic and environmental value of this project. The area of storage of ash and basalt waste, as well as emissions of industrial dust, can be reduced.

Acknowledgments

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