Investigation of the effects of fuel slag on the properties of gypsum mixtures

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Abstract. The article analyzes the effect of fuel slag on the properties of a gypsum binder. An optimal composition of a gypsum binder based on an ash and slag mixture has been developed in order to minimize costs, several compositions of plaster with different aggregates have been developed, an optimal composition has been identified based on the properties obtained. Gypsum binders and materials based on them are progressive building materials due to the simplicity, efficiency and low energy intensity of production. However, gypsum binders have high water demand, and products are characterized by low water resistance, limited strength, and low frost resistance.

1. Introduction
Gypsum products have a relatively small volume weight, non-combustibility and a number of other valuable properties. Gypsum products are used in precast construction, which allows you to industrialize the process of construction production. The disadvantages of gypsum products are a significant decrease in strength when wet, as well as creep, i.e. plastic (residual) deformations under load that increase over time, especially if the product is moistened, so gypsum products are not recommended for use in rooms with high humidity.

2. Relevance of research
The analysis of studies to improve the operational characteristics of gypsum materials shows that one of the ways to improve the technical properties of gypsum binders is to use chemical additives. Plasticizing additives help to modify various properties of gypsum binders.

Such additives including modern ones mostly developed for the cement systems do not have a high water-reducing effect in gypsum binders. Moreover, the presence of sulphonate groups and sulfate salts in plasticizer molecules accelerates their hardening [1-5].

There is a "line" of plasticizers and complex additives, adapted to the specific properties of gypsum binders. This specific character is due to the simultaneous processes of structure formation during the hardening of these binders, as well as the predominance of point contacts in the structure of a gypsum stone. When using superplasticizers on naphthalene formaldehyde and melamine formaldehyde, the best performance is achieved in the dispersion with the first type, due to its chemical structure, although the differences in the characteristics of gypsum stone are quite small. [6]

By weakening the forces of molecular interaction between the particles, due to a change in the zeta potential of their surface, additives of plasticizers contribute to their binding and denser packing.
Therefore, using them in gypsum dispersion, the most favorable conditions are created for intense interaction between the particles and the strength of individual contacts is increased. As a result of adsorption modification effect in the presence of plasticizers, a significant part of hydrates is formed in the form of the particles of high dispersion, which determines the formation of numerous fairly strong point contacts.

In the 80s of the 20th century, a trend related to the development of water-resistant composite gypsum binders of low water demand has been developed, this technology involves the use of plasticizing and pozzolanic admixtures in combination with mechanical and chemical activation of binder components [7-8].

A wide range of materials of natural and man-caused origin are used as pozzolanic admixtures to composite gypsum binders. A number of studies have revealed the efficiency of introducing composite gypsum and anhydrite binders with hybrid mineral additives, for example, ground blast furnace slag and tripoli powder [9], zeolite bearing rocks and limestone [10], zeolite bearing rocks and silica fume. [11]

A review of the references has shown that ash and slag mixtures have not been used to study the effect on the structure and physical and mechanical properties of a gypsum stone [12-16].

The joint effect of the ash and slag mixture and plasticizers on the physical and mechanical characteristics of a gypsum stone has not been investigated as well. From this perspective the topic of research is quite relevant.

3. Aim
The aim of the study is to investigate the effect of fuel slag on the properties of gypsum mixtures.

4. Tasks which were to be solved:
To identify the relevance of the selected topic of research, we have examined the existing studies on gypsum characteristics and properties. The data on the effect of various additives on the properties of gypsum and its setting time have been studied. The effect of various fillers is examined, and the optimal composition is revealed.

5. Theoretical part
Gypsum binder of G4 grade, SP-1 additive, stone crushing screening fractions of 0.63-0.315 mm, quartz sand fractions of 0.63-0.315 mm, acidic ash and slag mixture are used as raw materials. All materials used meet the requirements of regulatory documentation [17-19].

To compare the effect of slag on the properties of the gypsum mixture, they have been introduced in a ratio of 25% and 50% by weight of gypsum. We take the ash-slag mixture and gypsum as a composite binder.

We use the superplasticizer SP-1 in a percentage of 0%, 0.5% and 1% by weight of the gypsum binder as an additive, affecting the properties of the gypsum binder. 100% gypsum without the additive SP-1 is used as a control sample (table 1).

For a more complete analysis of the effect of fuel slag on the setting and hardening time and strength characteristics, a two-factor experiment has been conducted using the following matrix (Table 2) [20]. The results of the experiment are shown in Table 3 and in Figures 1-4.

6. The practical importance
As a result of the research, it was found that the addition of slag has a positive effect on the properties of gypsum products, which opens up new opportunities in the production of construction materials using low-energy and resource-saving technologies, as it allows you to reduce energy consumption for molding products. The resulting plaster gypsum dry construction mix has increased physical and mechanical properties, and, at the same time, reduces the cost of the mixture by replacing part of the construction gypsum with slag.
Table 1. Effect of SP-1 and an ash-slag mixture on standard consistency and D-spread.

| Standard consistency     | Average D-spread, mm |
|--------------------------|----------------------|
|                          | SP1-0%   | SP1-0,5% | SP1-1% | SP1-0%   | SP1-0,5% | SP1-1% |
| gypsum-100%, ash-0%      | 85       | 85       | 85     | 170     | 265      | 310    |
| gypsum-75%, ash 25%      | 70       | -        | -      | 170     | 290      | 310    |
| gypsum-50%, ash-50%      | 68,5     | -        | -      | 172     | 285      | 290    |

Table 2. Experiment matrix. Results of the experiment.

| Variable factors | Ash and slag mixture | Additive |
|------------------|----------------------|----------|
|                  | Code value | Physical value, % | Code value | Physical value, % |
| 1                | 1         | 0              | -1        | 0              |
| 2                | 0         | 25             | -1        | 0              |
| 3                | 1         | 50             | -1        | 0              |
| 4                | -1        | 0              | 0         | 0,5            |
| 5                | 0         | 25             | 0         | 0,5            |
| 6                | 1         | 50             | 0         | 0,5            |
| 7                | -1        | 0              | 1         | 1              |
| 8                | 0         | 25             | 1         | 1              |
| 9                | 1         | 50             | 1         | 1              |

Table 3. Results of the experiment.

| №  | R of bending, MPa | R of compression, MPa | Setting time, beginning, min. | Setting time, end, min. |
|----|------------------|-----------------------|-------------------------------|-------------------------|
| 1  | 2                | 2,2                   | 3,9                           | 4,1                     | 13  | 15  | 19  | 21  |
| 2  | 1,76             | 1,97                  | 3,59                          | 3,79                    | 14  | 16  | 17,5| 19,5|
| 3  | 0,87             | 1,1                   | 2,05                          | 2,25                    | 18  | 20  | 20  | 22  |
| 4  | 1,7              | 1,9                   | 3,48                          | 3,68                    | 17  | 19  | 19  | 21  |
| 5  | 1,9              | 2,1                   | 3,74                          | 3,94                    | 16,45| 18,45| 18,2| 20,2|
| 6  | 1,07             | 1,27                  | 1,86                          | 2,06                    | 19  | 21  | 21,5| 23,5|
| 7  | 1,8              | 2                     | 3,63                          | 3,83                    | 19  | 21  | 20,4| 22,4|
| 8  | 1,9              | 2,13                  | 3,9                           | 4,1                     | 17,3| 19,3| 20  | 22  |
| 9  | 1                | 1,2                   | 1,88                          | 2,08                    | 8,5 | 10,5| 10,5| 12,5|
7. Conclusions

- With an increase in the amount of ash and slag mixture in the binder, the standard consistency decreases due to a decrease in the amount of gypsum, but the decrease is insignificant since particles of an ash and slag mixture have a porous structure;
- With the introduction of an additive in gypsum and gypsum-ash and slag binders, the average D-spread increases. The D-spread of gypsum-ash and slag binder with an ash and slag content of 25% is higher than that of a gypsum binder and slightly higher than the D-spread of ash and slag binder with an ash and slag content of 50%, due to the higher energy porous mass content;
- With an increase in the content of ash and slag mixture up to 25% in a gypsum-ash and slag binder, the setting time decreases due to an increase in the amount of water per gypsum fraction, since the rate of gypsum crystallization increases and an ash acting as a filler creates a denser structure. But with an increase in the ash and slag mixture to 50% in a gypsum-ash and slag binder, the setting time increases due to decompression of the structure;
- With an increase in the content of ash and slag mixture, the compressive and bending strengths are decreased due to decompression of the structure. In a gypsum-ash and slag binder with an ash and slag mixture content of 25%, with the addition of SP-1 additive, strengths are increased due to a change in the zero potential of their surfaces, which facilitates their binding and closer packing structure.

References

[1] Butt Yu M Sychev M M and V V Timashev 1980 Chemical technology of binders (Moscow: Vysshaya Shkola Press) p 472
[2] Sulimenko L M 2005 *Technology of mineral binders and products* (Moscow: Vysshaya Shkola Press) p 334

[3] Lesovik V S, Pogorelov S A and Strokova V V 2000 Gypsum binding materials and products (Belgorod: BelGTASAM publishing house Press) p 224

[4] Volzhenskiy A V and Ferronskaya A V 1974 *Gypsum binders and products* (Moscow: Stroyizdat publishing company Press) p 328

[5] Baykov A A 1948 *Proceedings in the field of binders and refractory materials* vol.5 (Moscow: AS SSSR publishing house Press) p 272

[6] Garkavi M S 2005 *Thermodynamic analysis of structural transformations in binding systems* (Magnitogorsk: MSTU publishing house Press) p 243

[7] Koroviakov V F 2003 Gypsum binders and their use in construction vol. XI-УН Russian Journal of General Chemistry Press 4 18–25

[8] Ferronskaya A V (ed) 2004 *Gypsum materials and products (production and use)* (Moscow: ASV publishing house Press) p 488

[9] Volzhenskiy A V, Rogovoy M I and Stambulko V I 1960 *Gypsum-cement and gypsum-slag binding materials and products* (Moscow: Gosstroyizdat publishing company Press) p 162

[10] Khalilullin M I 1997 *Composite anhydrite binder with increased water resistance: author’s thesis for the degree of Candidate of Sciences (Engineering)* (Kazan: KSUAE publishing house Press) pp 34–35

[11] Sagdatullin D G, Morozova N N and Khozin V G 2009 Rheological characteristics of aqueous suspensions of a composite gypsum binder and its components (Kazan: KSUAE publishing house Press) 2 263–268

[12] Rakhimov R Z, Khalilullin M I and Gayfullin A R 2012 Composite gypsum binders using expanded clay dust and blast fuel slag Building materials Press 7 13–16

[13] Lesovik V S, Murtazasv S-A Yu and Saydumov M S 2012 *Building composites based on screenings for crushing concrete scrap and rocks* (Grozniy: FSUE "Groznensky Rabochiy" Publishing and Printing Complex Press) p 192

[14] Lesovik V S, Zagorodniuk L Kh and Chulkova I L 2014 The law of affinity of structures in materials science Fundamental research Press 3-2 267–271

[15] Shlenkina S S, Garkavi M S and Nova R 2007 The effect of plasticizers on hardening of gypsum binders Building materials Press 9 61–62

[16] Volzhenskiy A V, Ivanov I V and Vinogradov V N 1984 *The use of ash and fuel slag in the production of building materials* (Moscow: Stroyizdat publishing company Press) p 225

[17] State Standard GOST 24211-2008 Regional Standard Additives for concrete and mortar General specifications (Moscow: Standards Publishing Company Press) p 21

[18] State Standard GOST 23732-2011 Water for concrete and mortar (Moscow: Standards Publishing Company Press) p 11

[19] State Standard GOST 32021-2012 Dense rock aggregates for the production of dry mortar Specification Requirements (Moscow: Standards Publishing Company Press) p 10

[20] Shestakov A L, Sviridyuk G A, Butakova M D 2015 The Mathematical Modelling Of The Production Of Construction Mixtures With Prescribed Properties (Mathematical Modelling, Programming & Computer Software) Bulletin of the South Ural State University 1(8) 100–110