# A COMPLEX ORGANOMINERAL ADMIXTURE FOR CEMENT SAVING

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***Abstract:*** *The aim of the research is to prepare a composition of a complex organomineral admixture based on industrial waste for cement saving, to experimentally establish the optimum crushing degree of an ash-and-slag waste composition and to estimate the ratio between mineral and organic components of the complex admixture, ensuring the possibility of reducing cement consumption without loss of concrete strength. As a mineral component of the complex admixture the wastes from thermoelectric power stations were used, representing by an ash-and-slag waste composition crushed to a fine powder condition. Optimization of the complex admixture is carried out using mathematical methods of the theory of planning experiments.*

*As a result of this research a quadratic polynomial model of influence of crushing fineness of ash-and-slag wastes and cement consumption on concrete strength has been obtained. It is established, that depending on the degree of crushing of ash-and-slag waste composition within values of specific surface of received powder from 2400 to 4000 $cm^2/g$ it is possible to reduce cement consumption by 8-18 % without loss in strength of concrete. The introduction of complex organomineral admixtures into concrete is very effective as it saves cement. However, special studies are required in each case. The compositions of the new complex admixtures are tested on the basis of traditional raw materials, and economic efficiency in saving cement is established. It is proposed to use the methodology of mathematical modelling of the technological complex system under study, presented in this article.*

***Keywords:*** *organomineral admixtures, industrial waste, mathematical modelling, cement saving.*

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## Introduction

The problem of cement saving in construction is caused by the cement market conditions in the country. Cement plants in operation today were built during the Soviet era.

Existing cement plants have already reached their production capacity and yet are unable to satisfy the needs of the construction industry.

The establishment of new cement plants requires large investment outlays. The investment required to put each cement plant into production in total is around ₽7 billion over three years, which can only be recouped in 6-7 years [1]. The cement deficit today, due to the current geopolitical situation, cannot be overcome by imports. Another reason is that there are no special terminals for bulk cement loading. The transportation of imported cement by Railways is complicated by the inadequate capacity of the transport lines. This fact actualizes the problem of overall saving of cement in construction.

Saving cement is extremely actual when thinking about the environmental protection. It is estimated [2] that cement production will require about 5% of the world's industrial energy. At the same time, the production of each tonne of cement is associated with up to 1 tonne of carbon dioxide emissions into the environment, increasing the risk of global climate change.

The development of high-functional concretes provides an opportunity for significant cement savings [3-5].

High-functional concrete technology involves the use of complex organo-mineral admixtures (OMA). Such admixtures consist of highly dispersed mineral components and organic modifiers [6-8].

OMA are becoming increasingly widespread in construction practice, as the use of effective superplasticisers as organic components increases.

Mineral components of OMA can be various industrial wastes (keramzite dust, opoka, microsilica, etc.), as also finely crushed metallurgical slags, brick scrap, fuel wastes from thermal power stations and many other industrial mineral wastes. The selection of mineral component for OMA requires special research and depends on specific local conditions as well as on technical and economic efficiency of the results obtained.

In the research study prospects of obtaining an effective organomineral admixture using finely crushed ash-and-slag waste of Novocherkasskaya thermoelectric power station as a mineral component are considered.

**Materials and research methods**

The base material - the composition of concrete, developed and prepared at the enterprise LLC "BETON DON", Rostov-on-Don for technology of monolithic house-building. The prepared concrete mixture has the workability grade P4, is delivered to the construction site by concrete mixers, is delivered by concrete pumps to the formwork.

The basic consumption of components for concrete mixture preparation was as follows: cement - 350 kg/m$^3$, sand - 690 kg/m$^3$, crushed stone - 1120 kg/m$^3$, water - 200 l/m$^3$, superplasticizer additive - 7 kg/m$^3$ (2 % of cement consumption).

**Material Consumption**

Portland cement CEM I 42,5H of Sebryakov cement plant was used as a binder for the preparation of concrete mixture of mark B25/P4.

As a coarse aggregate used fraction 5-20 mm of crushed stone from Potapovsky sandstone quarry, Rostov region, grade 1200 of crushability.

The fine aggregate was sand of Leventsovskoye sand quarry in Rostov region with particle size modulus Mk = 1.56.

Superplasticizer from «Sky Trade Company» St 2.1 in accordance with TU 5745-004-9459066-2012 was adopted as an organic component for OMA. Superplasticizer is a solution of 25 percent concentration.

The technology of preparation of concrete mixture with the proposed OMA differed from the initial one in that instead of a part of cement consumption the corresponding amount of preliminary crushed ash-and-slag waste of Novocherkasskaya thermoelectric power station was introduced into the mixer.

In developing and optimizing the composition of OMA on the basis of the studied source materials it was necessary to identify the optimum fineness of ash and slag composition, characterized by the value of specific surface area (S, cm$^2$/g). It is also necessary to establish the maximum possible value of replacement of cement in the initial composition of the concrete mixture with the proposed OMA without loss of concrete strength.

**Subject matter and problems of the research**

Ash-and-slag wastes of thermal power stations are formed at combustion of pulverised solid fuel in furnaces of boiler units. At Novocherkasskaya thermoelectric power station fine grinded hard coal from the Donetsk coal basin is used.

The removal of ash and slag to the dumps is done hydraulically. In this process ash and slag are usually mixed in slurry pipelines and transported to special ash and slag dumps.

During the exploitation of Novocherkasskaya thermoelectric power station, one of the largest in Europe, more than 40 million tons of ash and slag wastes have accumulated.

Considering the huge resources of ash and slag waste in the dumps, expanding their use for practical purposes is of great environmental and economic importance.

So, the task of this research was to experimentally study the possibility of obtaining OMA on the basis of waste ash and slag waste, providing a reduction in cement consumption without loss of concrete strength.

To decide the problem we used methods of the theory of planning experiments. These methods allow us to find optimal solutions in the study of complex systems under statistical indeterminacy.

By setting up experiments according to one or another mathematical plan of experiment, the corresponding statistical processing of experimental data allows to obtain a polynomial model of the studied dependence in general form:

$$y = b_0 + \sum_{i=1}^{n} b_i\, x_i + \sum_{ii=1}^{m} b_{ii} x_{ii}^2 + \sum_{ij=1}^{k} b_{ij}\, x_i x_j, \quad (1)$$

where:

| | |
|---|---|
| y | - the response function under study, |
| $x_i, x_j$ | - coded values of the i-th and j-th factors, |
| $b_i$ | - required coefficient of the i-th factor, |
| $x_{ii}^2$ | - quadratic term of equation (1) for the i-th factor |
| $b_{ii}$ | - required coefficient of the quadratic factor i, |
| $x_i x_j$ | - interaction effect of the i-th and j-th factors, |
| $b_{ij}$ | - the required coefficient of the interaction effect of the factors. |

In this study, the response function $y$ for model (1) was the relative strength of the concrete:

$$y = \frac{R^{28} i}{R^{28}{}_{contr}} \cdot 100\ . \quad (2)$$

The influencing factors on the strength of concrete with the OMA were taken:

X1 - a part of cement consumption reduced due to the corresponding amount of OMA introduced into concrete composition in the range of 5-25 % ,

X2 - a degree of ash and slag dispersion characterized by specific surface value (S) in the range of S = 2000 - 4000 $cm^2/g$.

For mathematical modelling of concrete strength dependence on research factors $y = f(X1,\ X2)$ a modelling Box and Wilson's second-order plan on a regular hexagon [10] was used, which allows to obtain a quadratic model of the system under research by the results of 7 experiments.

## Results and Discussion

The planning matrix and the results of the experiment are presented in the Table.

**Table**. Planning and results of the experiment

| № | Plan | | Analysis Matrix | | | Result |
|---|---|---|---|---|---|---|
| | X1 | X2 | X1 X2 | X12 | X22 | $y = \frac{R^{28} i}{R^{28}{}_{contr}} \cdot 100$, % |
| 1 | - 0.5 | - 0.87 | 0.43 | 0.25 | 0.75 | 90 |
| 2 | 0.5 | - 0.87 | - 0.43 | 0.25 | 0.75 | 87 |
| 3 | - 1 | 0 | 0 | 1 | 0 | 114 |
| 4 | 0 | 0 | 0 | 0 | 0 | 101 |
| 5 | 1 | 0 | 0 | 1 | 0 | 90 |
| 6 | - 0.5 | 0.87 | - 0.43 | 0.25 | 0.75 | 110 |
| 7 | 0.5 | 0.87 | 0.43 | 0.25 | 0.75 | 100 |
| $\sum_{i=1}^{7}$ | (1y) - 30.5 | (2y) 28.7 | (12y) - 3.0 | (11y) 300.75 | (22y) 290.25 | (0y) 692 |

The realisation of the experimental plan presented in the Table allows to calculate the unknown coefficients of the polynomial model (1), which for two factors in our casework has the form:

$$y = 101 - 10.2x_1 + 9.6x_2 - 4x_1x_2 - 6x_1^2 + x_2^2\ . \qquad (3)$$

Model (3) mathematically describes a response surface in the factor spectrum under research. For interpretation of the new function, a geometric image of the response surface under study is constructed.

The Figure presents the geometrical image of the researched response surface in the form of isolines (lines of equal output) on the factor plane (similar to the way mountains or sea hollows are depicted on the geographical maps).

Analysis of the geometric image of the obtained mathematical model (shaded area of the Fig.) demonstrates that the introduction of the developed OMA in an amount from 8 to 18 percent of the volume of cement provides its saving without loss of concrete strength.

In this case, the higher the grinding degree of ash-and-slag waste is, the greater the cement saving is.

However, increase in grinding fineness increase energy consumption and reduces the effectiveness of grinding equipment.

Therefore, the choice of the optimal degree of ash-and-slag waste grinding is determined by technical and economic calculation, considering the specifics of local conditions.

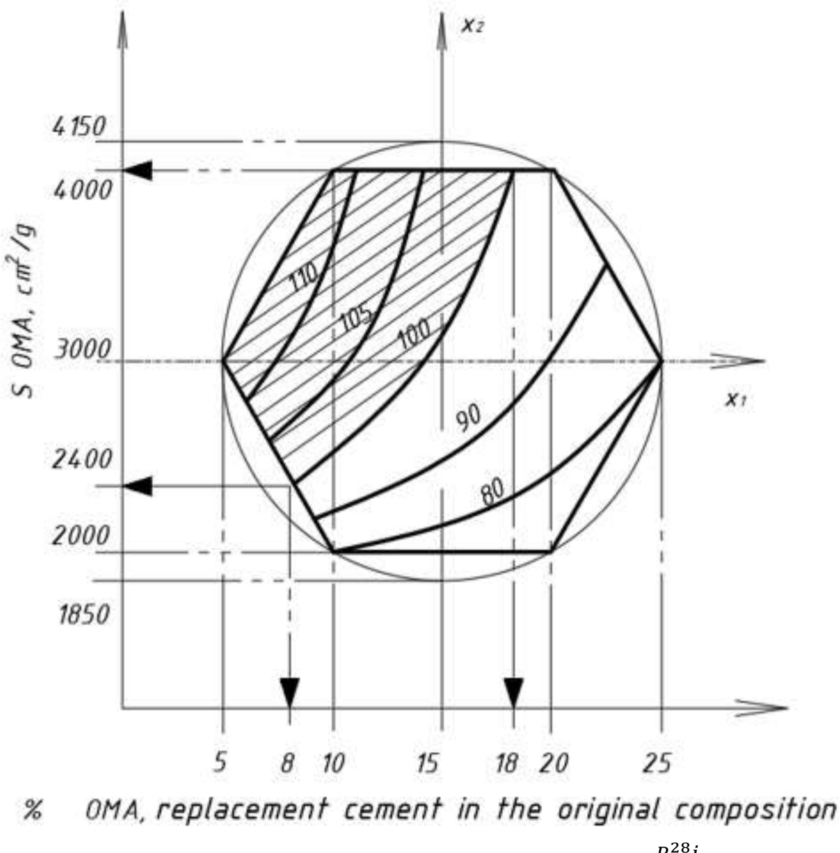


**Fig.** *Geometric image of the response function* $y = \frac{R^{28}i}{R^{28}{}_{contr}} \cdot 100$, %

**Conclusion**

The effective complex organomineral additive using ash and slag wastes as a mineral component has been developed. The total amount of ash and slag wastes at Novocherkasskaya thermoelectric power station exceeds 40 million tons and their use solves economical and ecological problems.

The methods of experiment planning theory made it possible to obtain a mathematical model and design its geometrical image. Integration of which allows, depending on the degree of ash-and-slag waste grinding and the consumption of the recommended admixture, to reduce cement consumption by 8-18% without loss of concrete strength.

It is advisable to use the methodology of the solution of this problem in further research aimed at expanding the nomenclature of organomineral additives based on waste products of sedimentary (limestone-slags, opoka, etc.) and volcanic rocks (tufa, perlite, pumice, etc.), which are local raw materials in the region.

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