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OPTIMIZING THE COMPOSITION QUALITY OF THE NON-FIRING LIMESTONE-SAND PHOSPHOGYPICAL MATERIAL

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Statement of the problem. The paper examines the problem of designing the optimal composition of a non-combustible limestone-sand phosphogypsum material for the production of wall composites and complete systems.

Results. The paper provides a statistical analysis of the study results identifying the properties of the final material based on the central two-factor experiment with central rotational planning. In order to increase the reliability of the results, the order of the experimental stages is randomized. The range of varying technological parameters is revealed; their effect on the strength properties of the non-combustible calc-gypsum phosphogypsum material is studied. The paper sets forth the analytical dependence which demonstrates a mutual influence of the initial values on the physical and mechanical characteristics. A regression equation, which presumes the covariance relationship of the energy parameters that vary with a comprehensive compression of the molecules and describing the physical interaction between particles in the process of structure formation is also presented. The area of a possible maximum strength of the non-combustible limestone-sand phosphogypsum material within the above analytical dependence of the strength of limestone-sand phosphogypsum material on technological parameters (pressing pressure and mixing time) is defined. It meets the operational requirements for wall and complete-type systems characteristics.

Conclusions. Following the appropriate studies, specific compositions of lime-sandy phosphogypsum material are proposed for the production of wall building materials based on non-burning phosphogypsum dihydrate technology. This provides the possibility of molding the resource-saving, efficient and environmentally friendly wall materials with specified performance characteristics: i. e. brick, block, partitions.

Keywords: statistical analysis, non-burning technologies, calc-gypsum phosphogypsum material, modeling.

Introduction. Tons of materials are industrially recycled resulting in huge amounts of wastes [8]. In particular, dehydrate-phosphor-gypsum is a large-capacity industrial waste of sulphuric acid.

While applying the sulphuric acid for recovering the apatite concentrate in 1 tonn of phosphorous acid H_3PO_4 there are from 4.3 to 5.8 tons of dehydrate-phosphor-gypsum depending on the type of raw materials and dehydrate.

Despite a great number of recycling technologies, only 0.3 mln t, or 1.5 %, out of 20 t of the annually obtained dehydrate-phosphor-gypsum is utilized and the remainder is removed as a waste and stored in dumps for decades with its physical and mechanical properties changing affected by the environment.

Therefore the issues pertaining to studies of the properties of dumped dehydrate-phosphor-gypsum followed by the design of materials based on it and generation of its new application technologies are still of importance [3—7, 15—20].

In order to examine the impact of various factors contributing to the formation of composite construction materials using the roasting-free technology relying on dehydrate-phosphor-gypsum, the mathematical approaches employing the experiment-planning methods were utilized [1, 2, 9]. An important role is played by the choice of parameters influencing the properties of materials with the technology parameters and taking the form of a regression.

1. Experiment. Based on the analysis of the studies using the major factors influencing the strength of composites, the following were accepted: *X*1 is the time of mixing of the raw mix, %; *X*2 is press pressure, MPa.

The choice has to be made as according to the theories, the structure of pressed construction composite materials based on phosphor-gypsum is formed using the contact and condensation mechanisms. For the latter there is a formation of joint crystallization planes of phosphor-gypsum, lime and sandy loam in certain ratios of their masses, time of technological mixing of a raw mix and application of press pressure.

All of these are compatible and not mutually correlated. Ranges of changes of the investigated factors are shown in Table 1.

Table 1

Ranges of changes in the input parameters

Planning conditions	Ranges of changes in the factors	
	*X*1, min	*X*2, MPa
Main level	75	15
Variation range	20	2.5
Upper level	115	25
Lower level	35	2.5

Choice of variation changes in the factors is due to the technological conditions of the solution and contact and condensation solidification as well as technological capacities of pressing. The criterion for the assessment of the influence of a variety of factors on the formation of the structure was *Y,* i.e. the compression strength limit of composite construction materials involving phosphor-gypsum after 28 days of solidification.

The research plan was generated into an experiment planning matrix (Table 2).

Table 2

Planning matrix and the results of the experiment in the obtained values

Number of an experiment	*X*1, min	*X*2, MPa	*Y*, MPa	Number of an experiment	*X*1, min	*X*2, MPa	*Y*, MPa
1	115	25	14.5	26	115	7.5	5
2	75	22.5	18.06	27	55	2.5	5.5
3	55	15	12	28	75	12.5	8.88
4	35	25	17	29	75	7.5	6.74
5	75	10	8.88	30	115	17.5	14.5
6	35	15	12.24	31	115	5	4.16
7	75	20	18.06	32	95	25	16
8	55	12.5	9.16	33	95	5	5.5
9	55	20	15.5	34	95	15	11.24
10	95	10	8.06	35	35	5	8.06
11	75	5	6	36	115	20	14.74
12	35	20	13.24	37	75	2.5	5
13	55	5	8.6	38	75	25	18.34
14	115	2.5	2.14	39	115	22.5	14.24
15	75	17.5	18.34	40	55	22.5	17
16	35	22.5	15.72	41	55	17.5	13.74
17	115	15	10.5	42	95	20	15.5
18	115	10	7.5	43	95	17.5	14.5
19	95	22.5	15.74	44	35	10	11.5
20	55	7.5	8.06	45	35	2.5	6.74
21	115	12.5	7.78	46	95	7.5	5.5
22	95	2.5	2.78	47	35	17.5	13.5
23	35	7.5	8.6	48	95	12.5	8.06
23	35	7.5	8.6	49	55	10	11.5
24	75	15	11.5	50	55	25	18.88
25	35	12.5	11.5	—	—	—	—

2. Results of the experiment. As a result of statistical processing of the experimental data on the pressing strength, MPa, and time of mixing, min, a regression equation was obtained using the influence of the above factors.

The use of this kind of planning allows us to characterize the original dependencies as a third-order polynomial. The steepness of changes of the results indicate that there are some energetic processes occurring inside.

At the initial stage the gradients of the change in the parameters taking part in the experiment planning as well as the results were analyzed. In order to reduce the number of the corrected points, a plan of rapid ascent was used. The coefficients of the model were calculated based on the matrix ratio of the input parameters (Table 3):

$$B = 2\lambda_4\left(\left(k+2\right)\lambda_4 - k\lambda_2^2\right)^{-1}, \tag{1}$$

where λ_2, λ_4 are the connections of the covariation function:

$$\lambda_2 = \sum_{u=1}^{N} X_{iu}^2, \quad \lambda_4 = \frac{1}{3N}\sum_{u=1}^{N} X_{iu}^4 .$$

The calculation of the functional dependence of the strength indicated the influence of the two values, i.e. the temperature of both the second-order and third-order polynoms, on the result of the experiment. As the parameters that were not significantly dependent on each other turned out to correlate, in order to find an optimal solution, the functional dependencies of dispersion along the ascending path were analyzed,

$$\beta_{iu} = B/N\left(\left((k+2)\lambda_4 - k\lambda_2^2\right)\sum_{u=1}^{N} X_{iu}^2\bar{y}_u + (\lambda_2^2 - \lambda_4)\sum_{u=1}^{k}\sum_{u=1}^{N} X_{iu}^2\bar{y}_u - 2\lambda_2\lambda_4\sum_{u=1}^{N}\bar{y}_u\right). \tag{2}$$

The points were corrected using the method of the alignment of the measurements and as the plan is not complicated, a standard method of testing a model using non-displaced assessment and dispersion of observation errors was used:

$$\sigma_R{}^2 = S_R \,/\, [N - (k+1)(k+2)/2] .$$

As a result, a third-order equation was obtaimed with mutual parameters of the temperature $T = X1$ and pressure $P = X2$ (Table 3):

$$\begin{gathered} Y = K_{12} + TK_{11} + T^2K_{10} + PTK_9 + PTK_8 + PT^2K_7 + \\ + P^2K_6 + P^2TK_5 + P^2T^2K_4 + P^3K_3 + P^3TK_2 + P^3T^2K_1 \text{ МПа.} \end{gathered} \tag{3}$$

This polynom describes a physical interaction between the particles of the formed lime and sandy loam phosphor-gypsum material. The use of the regression equation allows us to optimize the technological process and control the specified properties of the material.

Table 3

Coefficients of the equation (3)

$K_1{\times}10^{-7}$	$K_2{\times}10^{-5}$	$K_3{\times}10^{-3}$	$K_4{\times}10^{-5}$
4.22906	−6.766495953	−1.99014586676	−1.5215618e-05
$K_5{\times}10^{-3}$	$K_6{\times}10^{-2}$	$K_7{\times}10^{-5}$	$K_8{\times}10^{-2}$
2.43449886309	7.160290767428	6.9347586	−1.109561368293
$K_9{\times}10^{-1}$	$K_{10}{\times}10^{-4}$	$K_{11}{\times}10^{-2}$	K_{12}
−3.2634157861956	−3.7457774200	5.993243830371	1.76271877207132

Fig. 1 shows an approximation dependency of the compression strength of the and sandy loam phosphor-gypsum on the pressing pressure, MPa, and time of mixing, min.

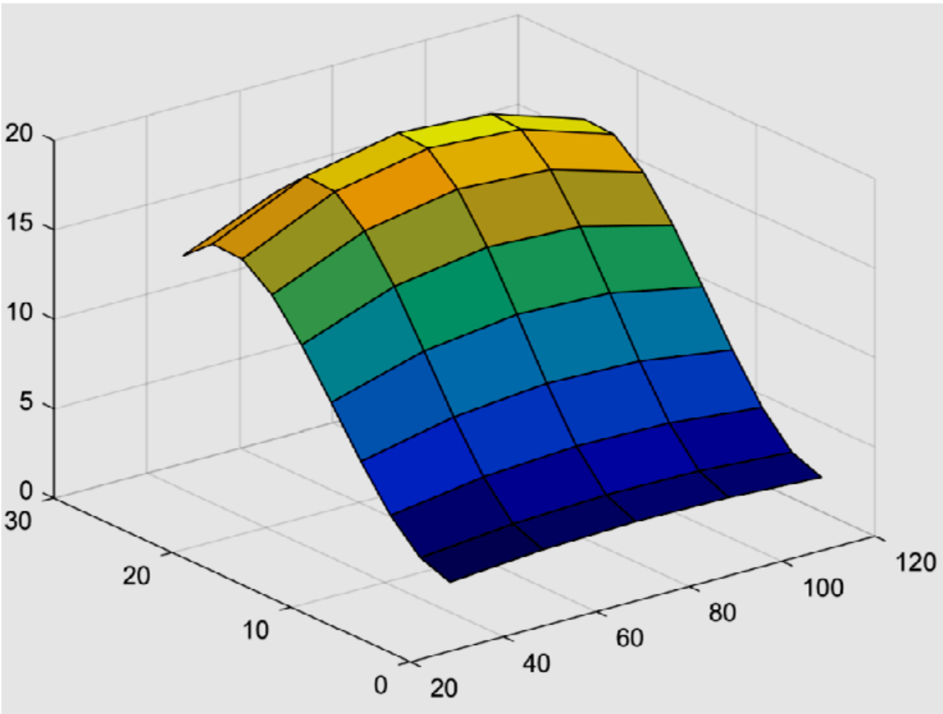

Fig. 1. Approximation dependence of the strength on the pressing pressure, MPa, and time of mixing, min. The energy of the connection is represented with a dependence quadratic function on the time of mixing of the mix and the compression of the molecules during the pressing from all sides is similar to a cubic polynom, which corresponds with the area of a maximum set of the pressing pressure strength of 21,7 MPa and the time of mixing of the mix of 82 min. In the range of 0 to 10 MPa there is a small gradient of an increase in the strength, which is due to another packing of the mineral particles. A further increase of the pressing pressure of over 22 MPa does not increase the strength, which is due to the typical composition of the lime and sandy loam phosphor-gypsum material

Fig. 2 shows a model dependency of the strength on the pressing pressure, MPa, and time of mixing, min.

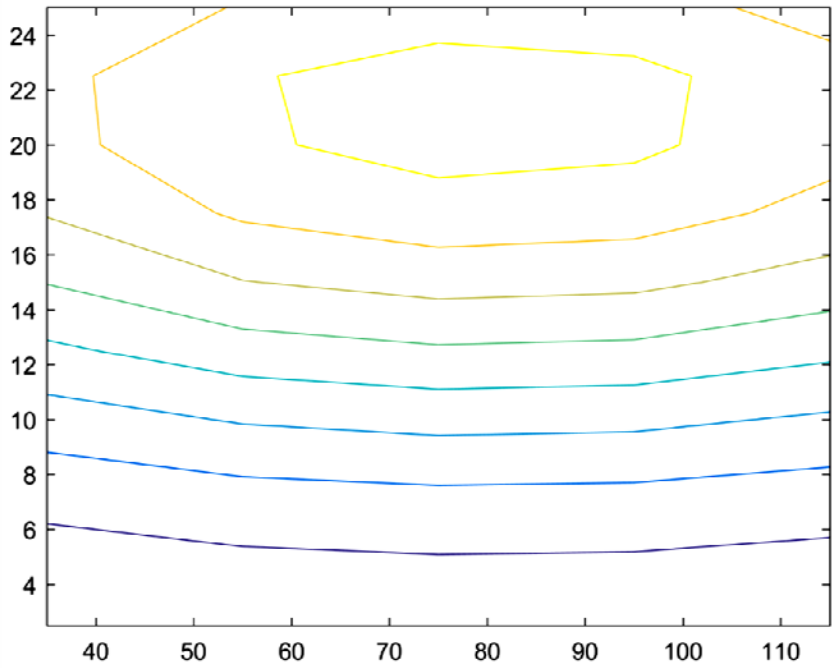

Fig. 2. Model dependency of the strength on the pressing pressure, MPa, and time of mixing, min. The maximum strength of the examined material corresponds with the point of an optimal solution of the equation with the pressure of 21.75 MPa and the time of preliminary mixing of 82 min

Conclusions. The research methoв is presented which is used to obtain the analytical dependence of the strength of the lime and sandy loam phosphor-gypsum material on the technological parameters (pressing pressure and time of mixing) where the energy of the connection is presented as a quadratic function of the dependence of time on mixing of the mix and the compression of the molecules from all sides is similar to a cubic polynom, which shows the range of the maximum set of the strength under the pressing pressure of 21.7 MPa and time of mixing of the mix of 82 min.

In the range of 0 to 10 MPa there is a small gradient of an increase in the strength, which is due to another packing of the mineral particles. A further increase of the pressing pressure of over 22 MPa does not increase the strength, which is due to the typical composition of the lime and sandy loam phosphor-gypsum material

The use of this research method would allow the technological process to be optimized and the specified properties of the lime and sandy loam phosphor-gypsum material to be controlled.

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