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RATIONAL RESEARCH METHODS FOR OPTIMIZING SOLAR THERMAL-CHEMICAL TREATMENT MODES FOR HIGHLY FILLED ASH-CEMENT COMPOSITIONS OF FINE-GRAINED STRUCTURE

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Abstract
The transition to the production of naturally hardened stones or those hardened under conditions of heat and moisture treatment using solar energy will increase purchasing power and consumer demand for wall materials, modernize or create production facilities with minimal investment and increase the volume of production of individual wall materials, reduce the consumption of conventional fuel for their production by about 350 thousand tons, and electricity by 400 million kW/hour.
In this aspect, the development of energy- and resource-saving technology for obtaining highly filled gold-cement materials and obtaining various products on their basis with their subsequent heat and moisture treatment using solar energy is of great scientific and practical interest.

Keywords: Thermal power plant, fly ash, ash-cement, granulation, solar energy, vacuum pump mixer, modified plasticizing additive.

Introduction

The relevance of the work. In the process of transitioning the economy of the Republic of Uzbekistan towards intensive development, significant importance is placed on the development, implementation, and further advancement of highly efficient, energy-saving, and environmentally sound technologies. This represents a crucial direction in the current stage of scientific and technological progress.

Analyzing the data on the comparative energy consumption for the production of one thousand units of standard brick, specialists from JSC "Uzkurilishmateriallari"

The transition to the production of naturally hardened stones or those hardened under conditions of heat and moisture treatment using solar energy will increase purchasing power and consumer demand for wall materials, modernize or create production facilities with minimal investment and increase the volume of production of individual wall materials, reduce the consumption of conventional fuel for their production by about 350 thousand tons, and electricity by 400 million kW/hour.

In this aspect, the development of energy- and resource-saving technology for obtaining highly filled gold-cement materials and obtaining various products on their basis with their subsequent heat and moisture treatment using solar energy is of great scientific and practical interest..

Furthermore, there is a need to synthesize numerous newly established specific patterns and, based on them, develop a theory and technology for managing the structure formation of ash-cement binding materials and products.

Solving this scientific and technical problem will allow for the identification of internal reserves to increase production efficiency through heliothermal chemical processes, primarily affecting the structure-forming environment, and determine ways to optimize them.

It is known that existing linear models inadequately describe the properties of fine-grained composite materials. Therefore, it became necessary to transition to planning a second-order experiment, which is generally described by a second-degree polynomial.

For gold-cement systems, the following variables were adopted as factors: isothermal heating temperature (X1) - in the range of 336 - 368 K with a step of 2880; preliminary holding time (X2) - 2 - 6 hours; isothermal heating duration - 8 - 16 hours.

The output parameter is strength (Rсж), as the most important indicator for products made of gold-cement materials of grades 75 and 100 after solar thermal chemical treatment:

with MPD – 1:

$$R_{sj}^{75} = 5{,}02 + 1{,}26X_1 + 0{,}24X_2 + 1{,}02X_3 + 0{,}46X_1^2 + 0{,}09X_3^2 - 0{,}58X_1X_3,\ MPa;$$

$$R_{sj}^{100} = 5{,}68 + 1{,}58X_1 + 0{,}33X_2 + 0{,}98X_3 + 0{,}65X_1^2 + 0{,}34X_3^2 + 0{,}17X_1X_2 + 0{,}27X1X_3,\ MPa.$$

The analysis of the presented mathematical models showed that in terms of the significance of the influence on the strength of products made of gold cement materials, the studied variable factors are arranged in the following descending order: X1>X2>X3. In order to compare the solar thermal-chemical treatment modes, a regression model was built that reflects the optimal technology of thermal-chemical treatment depending on the coolant temperature (X1) - in the range of 358-418K with a step of 2880; coolant velocity - 1-3 m/s; the content of MPD from the mass of C + Z - 0.28-0.32% with a step of 0.02%. It was found that in terms of significance, the variable factors are arranged in the following descending order: X2>X1>X3.

with MPD – 2:

$$R_{sj}^{75} = 5{,}42 + 1{,}38X_1 + 0{,}62X_2 + 1{,}31X_3 + 0{,}72X_1^2 + 0{,}09X_3^2 - 0{,}51X_1X_3,\ MPa;$$

$$R_{sj}^{100} = 50{,}02 + 2{,}1X_1 + 0{,}52X_2 + 1{,}04X_3 + 0{,}69X_1^2 + 0{,}57X_3^2 + 0{,}23X_1X_2 + 0{,}34X_1X_3\ MPa.$$

with MPD – 3:

$$R_{sj}^{75} = 5{,}8 + 1{,}62X_1 + 0{,}81X_2 + 1{,}51X_3 + 0{,}82X_1^2 + 0{,}12X_3^2 - 0{,}38X_1X,\ MPa;$$

$$R_{sj}^{100} = 6{,}24 + 2{,}32X_1 + 0{,}71X_2 + 1{,}34X_3 + 0{,}81X_1 + 0{,}82X_3^2 + 0{,}43X_1X_2 + 0{,}64X_1X_3,\ MPa.$$

Полученные решения использовались при проектировании свойств и определении эффективности гелиотеплохимической обработки мелкозернистых золоцементных материалов полиструктурного строения classes B7.5÷ B15 (tables 5, 6).

Table 1 **Classification of gold-cement materials as objects of solar thermal-chemical treatment**

Class	Z:C ratio	Material consumption per 1 m^3, kg				Surfactants, % of cement mass	Density, kg/m^3	Turbulent processing time, min	Compressive strength, $R28_{sp}$, MPa		Coefficient of variation of strength, Vп, %	
		S	Ash	L	v				*	**	*	**
B 7,5	85:15	180	1020	51	475	0,32	1316	-	9,1	7,8	20,3	20,8
B 10	80:20	230	920	46	441	0,30	1360	-	11,8	10,3	17,6	19,7
B 12,5	75:25	290	870	43	430	0,30	1410	-	14,5	12,7	16,2	18,2
B 15	74:26	295	860	42	427	0,30	1530	60	16,5	15,2	12,2	14,6

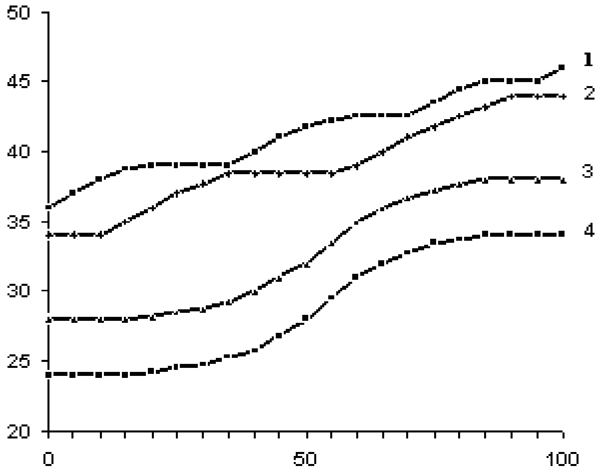
Note: * - intermittent heat treatment; ** - continuous heat treatment.

Table 2 **Physical and technical indicators of gold-cement products of class B7.5**

№	Ratio of components, %			Water consumption, kg/m^3	MPD supplement		Cone sediment, cm	B/T	Density, kg/m^3	Compressive strength, after 28 days, MPa
	cement	ash	lime		type	quantity, %				
1	15	81	4	465	MPD -2	0,30	18-20	0,376	1325	7,9
2	16	80	4	470	MPD -1	0,32	18-20	0,380	1335	8,0
3	18	78	4	462	MPD -3	0,28	18-20	0,380	1350	7,8

The structure-forming factors and their influence on the technical and strength properties of highly filled cast ash-cement mixture are considered. The ash-cement mixture does not contain large fractions of fillers and is a highly dispersed filled system. Consequently, it has a highly developed surface of the solid and liquid phases, which contributes to the development of intermolecular adhesion forces and increases the cohesion of the system as a whole, on the one hand, and on the other hand, requires a significant consumption of cement-water gel for coating ash particles. A sharp increase in water demand is associated not only with an increase in free and adsorption-bound liquid, but also with a high porosity of the ash particles themselves. Significant water demand of the highly filled ash-cement composition, as our studies have shown, negatively affects its hydrophysical, plastometric and thixotropic indicators. At the same time, theoretical studies of the influence of the degree of filling of the mixture on its water demand have shown that, contrary to the data given in various literary sources on the directly proportional relationship between water demand and ash content, a number of S-shaped curves have been obtained (Fig. 3). The phenomenon we have established requires a radical update of the existing energy technologies for the production of ash-cement materials of a polystructural structure..

The influence of additives on the water demand of gold-cement dough during heliothermochemical treatment

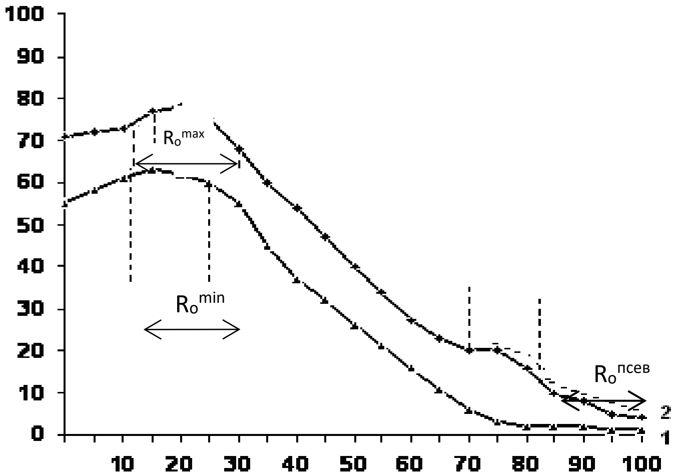


1 - with the addition of 10% lime; 2 - 5% lime; 3 - without additives; 4 - with the addition of 0.3% MPD-2

Fig. 3.

The experiments show that when mixing the binder and filler with water, a gilt-cement system is formed, the hardening process of which occurs at the level of microstructure formation. Its strength properties are determined by the processes occurring during contact between the solid and liquid phases, and depend on the amount of filler, the physicochemical activity of the particle surface and the heliothermochemical activation mode. With a filler content in the range of 70-80%, an interesting effect was first discovered, namely, the effect of reducing the strength of a highly filled structure (Fig. 4). This section is apparently the second zone of "pseudo-optimal" filling.

Compressive strength of gold cement products at the age of 28 days



1 - without additive; 2 - with MPD-2 additive
(0.3% of the weight of the mixed binder)
Fig. 4.

Along with physical processes in the filler-binder contact, there are also processes of chemisorption fusion of ash particles with cement. The nature of such interaction depends on the energy characteristics of the particle surface and an increase in contact adhesion, which can only be ensured by a complex - heliothermochemical action before and during the period of structure formation of multicomponent fine-grained materials of a polystructural structure. It was found that, according to the plasticizing effect, the optimal dosage of additives is located in the following descending row: MPD-1> MPD-3> MPD-2, which is 0.34; 0.30; 0.26%, respectively, for highly filled (more than 60% ash) ash-cement mixtures. The optimal lime content in the above system is 5-6%. The highest value of compressive strength at 80% filling was achieved with the introduction of 5% lime with MPD-1 (15.5 MPa); MPD-2 (15.1 MPa) and MPD-3 (13.7 MPa).

Modification of highly filled ash materials with MPD-1 and MPD-2 additives without lime under steady-state thermal action does not provide such a high effect of increasing strength, however, the obtained data are significant and amount to 11.5 and 12.3 MPa, respectively. It is shown that intermittent-pulsating thermal action with the introduction of the MPD additive provides an increase in the strength of an optimally filled ash-cement composition by 25-34%, while the kinetics of energy resource reduction in the range of 30-60% is observed.

It should be noted that for the modified system, the optimal degree of filling shifts towards an increase by 5-6% and amounts to 20-30%. The maximum increase in strength is 10-15%. At a water temperature heated in a solar collector to 305-312K, modification of the ash-cement material with additives provides an increase in bending strength by 20%, with optimal filling - 30%. A further increase in the temperature of the liquid medium and the degree of filling leads to a linear drop R_{28}^{pr} , and the "pseudo-optimal zone" is absent in this case.

From the point of view of combined mechanochemical and thermal effects, these phenomena can be explained as follows: at the optimum liquid temperature and turbulent mixing, significant velocity gradients arise in the mixture, viscosity decreases, thixotropic properties improve, and the dispersion of the system increases. When particles collide, the inert film is torn off their surface. The dispersion process provides free access of water to ash and cement particles, which leads to an increase in the number of hydrate neoplasms and a deeper hydration process..

Mathematical modeling of heliothermochemical processes of structure formation of gold-cement binders using solar energy. *When developing optimal heat and mass transfer modes for the purpose of intensifying the hardening of the mixture, it was found that, along with ensuring high quality of products, it also becomes possible to predict energy-based conditions of the technological process with economically optimal consumption of energy resources..*

Research has found an analytical relationship that takes into account the following factors:

- temperature rise at the calculated point due to internal heat generation taking into account the radiation absorption coefficient

$$\Delta t_{q_i}^{j-1} = \frac{m_v \cdot \Delta\tau}{c \cdot \rho} \cdot q_{э \cdot i}^{i^*} + q_l^i \cdot k_i,$$

where c is the specific heat capacity (830-870 W/mK), mV is the mass of cement in 1 m3 of concrete (180-295 kg/m3), ρ is the density of the product (1316-1530 kg/m3), is the intensity of heat release from cement hydration (W/m3), q_l^i - specific heat due to absorption of solar radiation, (Вт/м^3), k_l^i - absorption coefficient at 80% ash filling (0.81 W/m2K).

The amount of heat released into the volume of a product over time $\Delta\tau$

$$Q_{\text{э}}^{ij} = m_v \cdot \Delta\tau \int_V q_{\text{э}}^{j} \cdot dv + \frac{1}{k_i}\int_V q_{\text{э}}^{i} \cdot dv \approx m_v \cdot \Delta\tau \cdot \Delta x \sum_{j=1}^{K} Q_l^j + \frac{1}{k_i}\sum_{i=1}^{S} Q_l^i;$$

where j, i – index of the moment of time determined by the method of equal heat emissions and radiation absorption time.

Specific intensity of heat flow qэ generated in a combined solar power plant

$$q_F = -\frac{\lambda}{\Delta x}(t_r^{j-1} - t_1^{j-1}) + \Delta x \cdot \lambda \cdot c \cdot \rho (t_r^j - t^{j-1}) \cdot 0{,}5 - \lambda \cdot m_v \cdot \Delta x \cdot q_{\text{э}} \cdot 0{,}5 + \Delta x^2 + q\Delta x K_i$$

The amount of heat required to heat the product using solar thermal treatment

$$Q_F^{ji} = q_{\text{э}}^j \cdot \Delta\tau + q_1^i \cdot \Delta\tau + q_l^i \cdot \Delta r^1;$$

Efficiency ratio

$$K = \frac{Q_{\text{э}}}{Q_r} \cdot 100\%.$$

The calculation algorithm is implemented in the TURBO PASKAL 6.0 language for Pentium-4. The calculation time for each variant is 15-17 minutes. The results of the task for l1 l2 l3 were analyzed in three sections, which corresponded to points N2, N3 and N4.

The boundary indicators of the helio-thermally chemically treated ash-cement fine-grained product on interlayers were established (Table 3).

Table 3 Boundary indicators of helio-thermally-chemically treated fine-grained ash-cement product on interlayers

Boundary points	$L_1 = 0{,}1 \pm 0{,}001$ м			$l_2 = 0{,}2 \pm 0{,}001$ м			$l_3 = 0{,}4 \pm 0{,}001$ м		
	Δt^I, ^0C	t^I, ^0C	Q_e^I mdj	Δt^{II}, ^0C	t^{II}, ^0C	Q_e^{II} mdj	Δt^{III}, ^0C	t^{III}, ^0C	Q_e^{III} mdj
N_2	16,2	79,10	1,44	18,9	77,91	3,32	18,97	71,32	4,92
N_3	14,6	80,45	1,31	18,1	76,21	3,11	14,17	60,62	3,41
N_4	13,9	80,67	1,31	17,2	73,20	2,93	9,07	51,07	2,32

It is noted that the obtained data correlate well with the kinetics of heat release of ash-cement systems (Table 4).

Filling with ash by 20, 40, 60 and 80% reduces heat release by 17, 40, 50 and 57%, respectively. The introduction of MPD reduces heat release by 5; 6, 4; 8% in the following order MPD-1 > MPD-3 > MPD-2. This is explained by the selective adsorption capacity of modified plasticizing additives on the active centers of the surface of ash and cement particles.

As studies show, with an increase in thickness, the heating of the inner layers of the product significantly lags behind the heating of the outer layers. Therefore, the values of the maxima and the time of their appearance at the studied points of the product differ significantly from each other, which indicates the integral indicators of a fine-grained multicomponent product during heliothermochemical treatment (Table 5)

Table 4 Temporal indicators of heat release of gold-cement materials during heliothermochemical treatment

Timeframe for determining heat release, h	Temperature rise (0C) at ash content, wt.%				
	0	20	40	60	80
5	18	9	7	5	4
10	38	28	21	12	8
15	29	25	23	29	16
20	17	18	16	19	16
25	13	12	10	9	8
30	8	7	6	6	6
35	6	5	5	4	4

Table 5 **Integral indicators of helio-thermally-chemically treated fine-grained ash-cement product**

l, m	Q_e, kW/m^3	r^{max}, h	Q_e, mdj/m^3	Q^*, mdj/m^3
0,1±0,001	4,86	5	4,31	42,10
0,2±0,001	4,11	6	8,20	39,81
0,3±0,001	2,07	8	15,31	38,21

l, м	t, ^{0}C	Δt, ^{0}C	Q^*_f, mdj/m^3	τ,h	Q^*_e/Q^*_f,%	Q^*_e/Q^*_t,%
0,1±0,001	80,45	14,42	13,21	5	31,87	16,84
0,2±0,001	77,92	16,94	11,84	11	38,39	15,92
0,3±0,001	60,14	13,63	10,37	13	36,85	15,28

Analyzing the calculation results for fine-grained products of different thicknesses, we can note the following: the thickness of the product affects not only the quantitative characteristics of heat generation, but also changes its kinetics. It has also been established that the thicker the product, the more heat is generated in absolute units and the greater its share in the total amount of heat for heating. This is easily explained by the fact that with an increase in the thickness of the product, based on the specific area of the heated surface, an increase in the volume of the product is also observed. At the same time, it should be noted that there will no longer be such a direct dependence on the specific volume.

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