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Investigation into the Properties of Foamed Concrete Modified by Chemical Additives.

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ABSTRACT

We have developed keratin foaming agents, similar to German foaming agents for production of foamed concrete, which enable production of foamed concrete on the basis of domestic environmentally safe, more available and cheap foaming agents. It has been found that all foaming agents (synthetic and protein-based) efficiently decelerate cement hydration and, hence, decelerate structure formation of cement stone and concrete. In order to produce foamed concrete it would be reasonable to apply foaming agent in amount of 0.4% of cement weight with 1.5% of complex additive: Lignopan B-2 plus 0.5% CNN. However, foaming agent in amount of 0.5% of cement weight should not be disregarded, since such dosage increases the foam stability, that is, its viability. When foaming agent is used in amount of 0.5% of cement weight it is recommended to increase the content of cement hardener and accelerator of structure formation of foamed concrete up to 1.75%: Lignopan B-2 and 0.75% CNN. Increase in plastic strength decelerates with increase in content of foaming agent solution. When complex hardener Lignopan B-2 plus CNN is used, foamed concrete items can be demolded already in 40–50 min, when plastic strength achieves 0.16 MPa and 0.152 MPa at concentration of foaming agent solution of 0.4% and 0.5%, respectively. Excessive increase in plastic strength of raw foamed concrete up to 0.25--0.3 MPa is undesirable, since upon production of small wall components the strings of cutting apparatuses can be torn. The items with plastic strength of 150–200 g/cm^2 can be conveyed for steam curing without danger of their damage.

Keywords: foamed concrete, keratin, foaming agent, cement, modified additives, foam.

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INTRODUCTION

The major advantage of buildings made of cellular concrete is favorable microclimate inside the buildings, superior heat and sound insulating properties of enclosing structures.

Production of cellular concrete is developed according to two main trends: cellular aerated concretes of autoclave and non-autoclave curing.

However, production of the most efficient foamed concrete in terms of thermal-physical properties is restricted due to insufficient amounts of foaming agents, characterized by fine dispersity and high stability of foam.

Indian researchers analyzed compatibility of foaming agent with chemical additives in foamed concrete. Herewith, this composition of foamed concrete involved coarse filler and reinforcement including light fibers. In addition, experimental results on lifetime of foamed concrete and influence of various factors on the properties of foamed concrete are given [1].

Foamed concrete on the basis of three mixtures was studied including their structures and foam in cured state. The foamed concrete with compression strength of 0.74 MPa and heat conductance of 0.054 W/m was produced [2].

It was established in [3] that the use of foamed concrete decreases load on foundation, promotes power saving and reduces construction costs. Besides, the use of foamed concrete reduces estimated costs due to lower expenses for transportation in comparison with concrete.

A. A. Akhundov on the basis of practical researches arrived at conclusion that the production technology of foamed concrete is sufficiently uncomplicated in comparison with aerated concrete. The prepared cement and sand mixture is mixed with the foam produced in foam generator. After agitation of the concrete mixture with foam various building items are molded [4, 5]. in addition, this concrete is an excellent material for monolithic construction.

Among promising methods it is possible to mention the proposal by V. A. Martynenko to apply two-stage steam processing of items in battery molds, where the items are steam cured at the first stage, and the second stage involves short autoclave processing [6]. This technology also facilitates increase in turnaround of molds and reduction of footprint areas due to increased curing cellular concrete.

The work [7] provides reasoned arguments in favor of cellular concrete applied as heat insulating enclosing structures of resident and civil buildings.

G. P. Sakharov proposes original complex approach to solution of the problem of thermal protection of heated buildings based on application of foamed concrete stones with engineering cavities or thermal inserts made of foamed plastics. Average density of the stones with thermal inserts is 400-450 kg/m^3, and thermal conductance is by 15-17% lower than that of monolithic cellular concretes of the same density [8].

Development of efficient production technologies of cellular concrete is confirmed by the results obtained by S. A. Gusenkov, V. M. Smirnov, S. D. Galkina and V. S. Erofeev. These researchers developed advanced technology and up-to-date equipment enabling production of foamed concrete with the density from 400 kg/m^3 to 1200 kg/m^3, cured under ambient pressure. The produced foamed concrete items are efficient building material, which improves of heat engineering performances of erected buildings. The developed equipment is characterized by low power intensity and makes it possible to produce items with superior physico-mechanical and heat engineering performances [9].

A. I. Kharkhardin and L. S. Vesnin point at dependence of technical and economical performances of production of foamed concrete items on the type and properties of raw materials, foam activating substance and chemical additives, design of foam generator and quality of mold fabrication; the expenses for production of 1 m^3 of foamed concrete items are 161-362 rubles depending on the type of foamed concrete [10].

Taking into consideration advantages of foaming agents produced by German companies Neopor-System and Edama in terms of high stability of foams and disadvantages of Russian synthetic foaming agents with regard to their low viability, that is, high syneresis, we decided in favor of domestic keratin foaming agent, the physicochemical properties of which are similar to those of German products.

EXPERIMENTAL

The production technology of foaming agent includes hydrolysis of keratin raw stuff, we carried out this process in hydrothermal bombs made of chrome-nickel steel. The hydrolysis was performed at 130±5°C with addition of chemical reagents promoting complete dissolution of initial raw stuff. The obtained foaming agent was filtrated and then stabilized by various chemical additives aiming at achievement of the required properties of foaming agent.

Normal consistency of cement paste (the tests were performed with the Grade M 400 cements, since all information sheets of German companies Neopor-System and Edama recommend these cements) decreased in all cases irrespective on cement producer.

The foam generating ability of the obtained keratin hydrolysate was studied by the procedure similar to that proposed by Bickerman. The estimation criterion of gaom generating ability is the amount of foam obtained as a result of air bubbling via glass filter.

We started our studies of foam generating ability of the obtained protein-based hydrolysate from analyzing of its pH and surface tension. The pH value was measured by an EV-74 ion meter. The pH value in one day after production of the hydrolysate and its neutralization was in the range of 5.80–5.82. The density of the solutions was in the range of 1.0–1.015 g/cm^3. Surface tension was determined by the Wilhelmy plate method, based on determination of retraction force of platinum plate, stipulated by surface tension of the liquid.

The surface tension of solutions of various concentrations was determined in thermostatically controlled cell. The isotherms of surface tensions are summarized in Table 1.

Table 1. Isotherms of surface tension of keratin foaming agent solutions

Concentration,%	0.1	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
σ, N/m	58.9	54.6	47.3	45.7	44.5	41.3	37.9	37.3	36.8	36.5	36.5

RESULTS AND DISCUSSION

The experimental results on the influence of foaming agent (2.5% or 0.5% of cement weight) on normal consistency and setting time of cement paste are summarized in Table 2.

Table 2. Influence of foaming agent type on normal consistency and setting times of cement paste

Cements mixed with solutions of foaming agents of various manufactures	Normal consistency,%	Setting times, , hour-min	
		initial time	final time
Cement w/o foaming agent:			
Shymkent	26.3	3-35	6-10
Ust-Kamenogorsk	25.7	3-20	6-40
Cement mixed with 2.5% solution of Neopor System foaming agent:			
Shymkent	25.3	2-40	5-25
Ust-Kamenogorsk	24.9	2-10	5-10
Cement mixed with 2.5% solution of Edama foaming agent:			
Shymkent	25.5	2-45	5-30
Ust-Kamenogorsk	24.9	2-20	5-45
Cement mixed with 2.5% solution of our foaming agent:			
Shymkent	25.7	3-40	6-20
Ust-Kamenogorsk	24.5	3-35	6-15

The concentration of foaming agent of 2.5% was selected according to the recommendations of the German companies Neopor-System and Edama to apply such concentration of surfactants for production both of cellular foamed concretes with the density from 300 kg/m^3 to 1000 kg/m^3, and of concretes with porous cement stone with the density of above 1200 kg/m^3 and up to 1800 kg/m^3. In addition, our tests also demonstrated that at the concentration of foaming agent of 2.5% we achieve optimum foam expansion ratio of 13-14 and high stability of foams in the range of 180-200 min.

Experimental data summarized in Table 2 reveal that Neopor-System and Edama foaming agents shorten the initial time of cement setting by 24.2-38.7% and 14.3-31.3%, respectively. Application of these foaming agents also shorten the final time of cement setting by 13.9-27.2% and 13.1-20.0% for solutions of для растворов лей фирм Neopor-System and Edama foaming agents, respectively. The presented data about the influence of these foaming agents on normal consistency and cement setting times illustrate their favorable action on cement.

It was found that our protein-based foaming agent provides slight increase in both initial and final setting time of cement paste. For instance, the initial setting time increased by 5 min and 15 min for Shymkent and Ust-Kamenogorsk cements, which amounts to 1.5 and 4.7%, respectively. The final cement setting time increased by 10 min for Shymkent cement. On the contrary, the final setting time of Ust-Kamenogorsk cement decreased by 25 min, which is 4.0%, respectively. This can be attributed, probably, to experimental error, since the State Standard permits deviations in immersion depth of Vicat apparatus needle not higher than 1 mm.

Therefore, the tests demonstrated that upon mixing of cement with foaming agent solutions the cement paste is plasticized and the initial and final setting times are shortened with the use of German foaming agents. Upon mixing of cement with our foaming agents the initial setting time increases for all considered cements and the final setting time decreases for Ust-Kamenogorsk cement.

The data in Table 2 demonstrate that surface tension decreases with increase in the content of keratin foaming agent. However, reaching certain level of 3%, the surface tension is stabilized. Probably, this can be attributed to saturation of adsorption layers of double-sided films, which is an evidence of specific properties of protein-based surfactants. This peculiarity of protein-based surfactants is manifested in very slow reaching of equilibrium value of surface tension. Slow formation of equilibrium adsorption layer was attributed to diffusion of globular molecules into interface surface and expansion of polypeptide chain. This circumstance explains the empirically known fact of higher stability of foams of protein-based solutions in comparison with synthetic surfactants.

The foam expansion ratio of keratin foaming agent is in the range of 11–13 depending on the concentration of aqueous solution of foaming agent.

The syneresis (50% fluid outflow from the obtained foam) is in the range of 90–110 min.

Another stage of our studies was determination of influence of keratin foaming agent on the cement setting times.

The studies were performed according to regular procedure (on the basis of Vicat apparatus) with the only difference that instead of water for mixing of cement paste the solutions of foaming agent of specific concentrations were used. The tests were carried out with Ust-Kamenogorsk Portland cement, Grade 400 and Shymkent Portland cement, also of Grade 400.

The tests demonstrated that the solutions of foaming agent exposed plasticizing action on cement paste. Normal consistency of the cement paste decreased for both type of the binder. Experimental results on the influence of aqueous solution of foaming agent in amount of 2.0 and 2.5% (0.4% and 0.5% of cement weight) on normal consistency and setting time of cement paste are summarized in Table 3. The contents of foaming agent of 2.0% and 2.5% were selected because of the fact that the previous tests revealed the highest stability of foams and their optimum expansion ratio of 11–13 at the given contents of foaming agent.

It can be seen in Table 3 that addition of foaming agent into mixing water plasticizes the cement paste, water consumption reaches 7.1%. This is a valuable property of protein-based foaming agents, since it enables decrease in cement consumption in production of concretes, as well as reduction of moisture content in final foamed concrete items.

Table 3. Influence of foaming agent on normal consistency and setting time of cement paste

Cement producers	Normal consistency at foaming agent concentration,%		Setting times at foaming agent concentration, h-min			
	0.4% of cement weight	0.5% of cement weight	initial time		final time	
			0.4% of cement weight	0.5% of cement weight	0.4% of cement weight	0.5% of cement weight
Ust-Kamenogorsk	25.5	25.2			7 – 40	8 15
Shymkent	25.1	25.0	3 – 10	3 – 20	6 – 55	7 - 45

However, these foaming agents have certain drawbacks, which is exhibited in slight increase in initial and final cement setting times. For instance, the initial setting time of Ust-Kamenogorsk cement increased by 60–75 min, and final setting time by 30–60 min upon cement mixing with foaming agent solution in amount of 0.4% and 0.5%, respectively. Upon mixing of Shymkent cement with cautions of keratin foaming agent of the same contents the increase in initial and final cement setting times is 40 min and 75 min, respectively, and water consumption by cement paste is 8.5%.

Increase in the setting times of cements mixed with solutions of keratin foaming agent fromoт 30 min to 75 min is undesirable, since in this case the turnaround of molds decreases as well as the yield of a plant producing foamed concretes. The most pronounced negative effect occurs in the case of battery molds, when disassembling, cleaning, lubrication and assembling require up to 5–8 h of operation time.

Cutting technology is more promising, when large array is formed with the length up to 6 m, the height up to 0.6 m and the width up to 1.2 m. After gaining plastic strength this array is cut by means of short strings into blocks of required sizes and conveyed on tray into steam curing chamber. The main advantage of the cutting technology in addition to low metal intensity and high yield is the absence of the so called wall effect. This is one more evidence of advantage of cutting technology of cellular concretes.

Aiming at acceleration of structure formation of foamed concretes we selected complex additive composed of Lignopan B-2 plasticizer, which in addition to plasticizing effect accelerates hardening of concrete increases viscosity of foamed concrete mixture, plus calcium nitrate--nitrite (CNN), well-known accelerator of hardening, which additionally compacts the structure of inter-porous membranes of foamed concrete and increases its strength.

The tests were performed according to the procedure described above with the same cement grades and at the same concentrations of aqueous solutions of keratin foaming agent. The only difference in the tests was that upon preparation of cement paste the mixing water was added together with Lignopan B-2 in amount of 1.5%, and the content of CNN was 0.5% of cement weight.

The tests demonstrated that addition of these substances did not increase the normal consistency of cement paste and even slightly decreased this parameter, which is a positive fact. This is attributed to plasticizing effect of Lignopan B-2, which is composed of purified technical lignosulfonate [19]. The component of added substances (Lignopan B-2 and CNN) are well compatible, which is manifested by the absence of coagulum in aqueous solution and cement paste. The decrease in normal consistency of cement paste with the mentioned complex additive was 9.5--15%.

The experimental results on determination of setting times of these cements mixed with solutions of keratin foaming agent in amount of 0.4% and 0.5% with complex additive of Lignopan B-2 and CNN are summarized in Table 4.

Table 4. Influence of Lignopan B-2 and CNN complex additive on setting time of cement mixed with solutions of keratin foaming agent

Cement producers	Setting times at foaming agent concentration, h-min			
	initial time		final time	
	0.4% of cement weight	0.5% of cement weight	0.4% of cement weight	0.5% of cement weight
Ust-Kamenogorsk	0 – 50	1 – 10	2 – 45	3 – 05
Shymkent	0 – 45	0 – 55	2 – 15	2 - 55

It follows from Table 4 that the initial setting time of cement paste with the complex additive mixed with 0.4% aqueous solution of keratin foaming agent decreased by 2 h 25 min for Ust-Kamenogorsk cement and by 2 h 20 min for Shymkent cement in comparison with initial values of setting times of these cements.

The obtained results reliably evidence the efficiency of the proposed complex additive consisting of Lignopan B-2 and CNN. Using this additive it possible to perform two fillings of foamed concrete per shift, that is, to increase the turnaround of molds and production rate by two times in the case of battery molding of foamed concrete blocks.

Study of reaching plastic strength by raw foamed concrete with addition of accelerator of hardening and structure formation is highly interesting from theoretical and practical points of view.

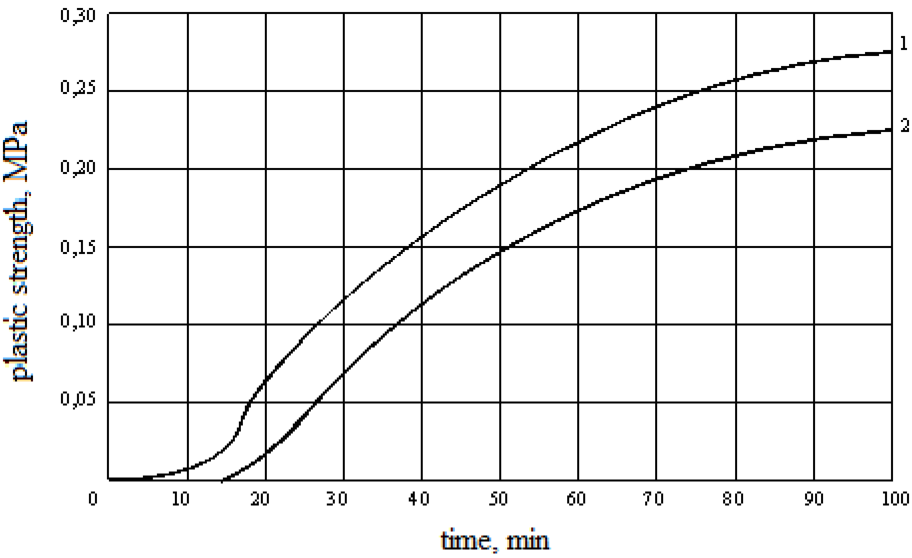
The study was performed with samples of foamed concrete mixture, where according to calculations the average density of cured foamed concrete should be 600 kg/m^3. Such density of foamed concrete was selected not at random, since this is an engineering thermal insulating material highly popular with building companies. Concrete of such density at low coefficient of thermal conductance (0.14 W/(m·°C) has sufficient strength: from B1 to B2.

The rate of gaining plastic strength of raw foamed concrete was studied using a conic plastomer developed by Academician P. A. Rebinder.

Previously study of fluid outflow rate from foam, produced by foam generator, under the pressure of compressed air of 0.6 MPa demonstrated that 50% of liquid outflows in 90–110 min in the case of keratin foaming agent in amount of 0.4% and 0.5% of cement weight, respectively, since the keratin foaming agent increases the initial and final cement setting times by about 1 h. Application of the complex additive, which accelerates hardening and structure formation, decreases the initial and final cement setting times by about 2 h (initial setting time) and 4 h (final setting time), and the study of kinetics of plastic strength of raw foamed concrete is of great concern.

The study of kinetics of plastic strength of foamed concrete is required for accurate determination of demolding time and start of array cutting into smaller blocks.

Figure 1 illustrates plasticity patterns of raw foamed concrete, produced on the basis of keratin foaming agent in amount of 0.4% and 0.5% of cement weight. The concentration of the complex additive, hardening accelerator, in both cases was 1.5% Lignopan B-2 plus 0.5% CNN. We deliberately applied constant consumption of hardening accelerator aiming at determination of its influence on the gaining rate of plastic strength of foamed concrete at various concentrations of foaming agent solution.



1 – Concentration of foaming agent solution, 0.4% of cement weight;
2 - Concentration of foaming agent solution, 0.5% of cement weight

Fig. 1. Kinetics of strength generation of raw foamed concrete.

CONCLUSIONS

- The given physiochemical properties of our keratin foaming agents are comparable with those of German foaming agents for production of foamed concretes and enable production of foamed concretes on the basis of domestic environmentally safe, more available and less expensive foaming agents.
- On the basis of the performed tests it can be concluded that in order to produce foamed concrete it would be reasonable to apply foaming agent in amount of 0.4% of cement weight with 1.5% of complex additive: Lignopan B-2 plus 0.5% CNN. However, foaming agent in amount of 0.5% of cement weight should not be disregarded, since such dosage increases the foam stability, that is, its viability.
- Analysis of plasticity patterns shows that with increase in concentration of foaming agent solution the increase in plastic strength decelerates. When complex hardener Lignopan B-2 plus CNN is used, foamed concrete items can be demolded already in 40–50 min, when plastic strength achieves 0.16 MPa and 0.152 MPa at concentration of foaming agent solution of 0.4% and 0.5%, respectively. It has been established that in the sample without accelerating additive plastometer recorded zero plastic strength in the considered time range (from 0 to 50 min).

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