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Obtaining Foam Concrete Applying Stabilized Foam

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Abstract

Objectives: The objective of this study is to obtain better quality foam concrete. In the process of preparing protein-based foam the technique of stabilizing foam with colloidal sol solutions is used. **Methods:** The idea of stabilization implies the following: The interaction at the boundaries between the foam layer phase and the colloidal sol phase becomes possible if silica sol or iron-bearing sol is used. This interaction results in generating the complexes that increase strength of the foam and that of the foam concrete slurry and thus improve the properties of the resulting foam concrete. **Findings:** The study investigates the parameters that characterize different limitations on manufacturing foam concrete for construction purposes and shows the achieved levels of changing basic structural and technical properties. Besides, the methods of instrumental analysis are used to demonstrate the phase changes occurring in the non-autoclaved foam concrete when stabilized foam is used in the process. The study also shows the possibility to increase the strength of the items made of foam concrete employing the methods of penetration surface treatment with silica sol solution and iron-bearing sol solution. Apart from structural and technical properties, the study also considers geoecological protective properties of foam concrete. **Applications/Improvements:** The results of the study can be used in commercial production of normally cured foam concrete with improved performance characteristics.

Keywords: Colloidal Sol, Foam, Foam Concrete, Geoecological Protective Properties, Stabilization, Silica Sol

1. Introduction

Cellular materials in the form of foam concrete are among those in high demand thanks to their good heat retention properties and their appropriateness for low-height construction which is important from the perspectives of environmental protection as the improved thermal characteristics help save fuel, energy and mineral resources. The process of manufacturing foam concrete is associated with the problem of the short life of the foam that should be made longer applying, for example, stabilization processes. There are many different methods of foam stabilization among which stabilizing with special additives can be distinguished; to improve foam stability different types of additives can be applied taking into account the ideas described below[1,2].

Foam system possesses much greater surface area as compared to its volume; therefore the stabilizing additives can also be represented by the systems featuring high specific surface area. It is a well known fact that the thickness of the film in the foam amounts to 2…100 mill micron and thus, to protect the film in the foam from destruction, the substances with comparable sizes of the particles should be used. Colloid solutions in the form of sols are represented by the substances whose sizes of particles are within the range of 1…100 millimicron and they do possess large specific surface area. The peculiar feature of sols is that their particles possess the structure that enables the interaction between the particles of sol with the particles of the foaming agent water solution. This could increase the viscosity of the system and prevent the liquid from leaking out of the foam film.

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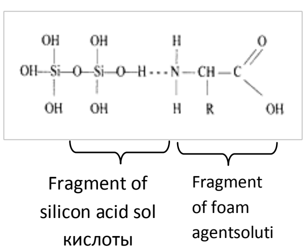
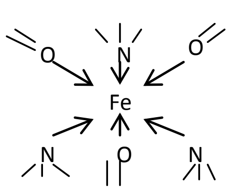
Over the last decades the commercial methods of obtaining the highly disperse concentrated silica sols with different ranges of pH-values have been developed; the particle sizes of those substances are in the range of 5 … 25 milli micron, and the concentration of the disperse phase in them makes up to 40 %. Production of colloidal sols of different types and nature is founded on the dispergation and condensation methods. As example by silica sol, the general pattern of polymerization and gel formation can be represented as follows (3): $Si(OH)_4$ → colloid particles (sol) → grid of particles (gel). The principal chemical process in obtaining silica sol is represented by the reaction of polyfunctional condensation (4). This reaction predetermines generation and growth of sol formations and it is a complex process where chemical reactions are accompanied by different physical processes: phase formation, isothermal re-conservation, coagulation and gel formation. Hydrated silica is a weak acid that exists only in diluted solutions at concentration values < 0.011 g/l with pH ranging from 1.0 to 8.0 and it can be obtained as a result of the reaction of sodium silicate Na_2SiO_3 hydrolysis according to the pattern as follows: $Na_2SiO_3 + 3H_2O \leftrightarrow Si(OH)_4 + 2NaOH$. Hydrated silica disengaged as a result of the reaction consists of four equal silanol groups (≡ Si – O – H), which in turn can form siloxane linkages (≡ Si – O – Si ≡) that lead to the formation of polycilicic acids of linear or divergent structure. The schematics of polyfunctional condensation are shown below:

$$(OH)_3 \equiv Si - OH + HO - Si \equiv (OH)_3 \rightleftarrows (OH)_3 \equiv Si - O - Si \equiv (OH)_3 + H_2O.$$

Thus, in water solution there are both mono- and polymeric types of hydrated silica that can be interconnected by Van der Waals forces, by hydrogen or siloxane linkages. This fact ensures generation of the new phase formations. Then the reaction of polyfunctional condensation

Table 1. Supposed influence of the foam stabilization and foam concrete surface processing with nanoadditives on the quality of foam concrete and its products

Stabilizer	The system of foaming agent solution and nano-additives from sols		The system of the surface layer of foam concrete and nano-additives from sols	
	The mechanism of interaction and the formation of stabilization complex	Supposed impact on the properties of foam concrete and its products	The expected mechanism of introduced sol and interaction foam concrete surface and its products	Supposed influence on the quality of foam concrete and its products
Silicon acid sol	Silicon protein complex 	1. Increasing foam stability, foam stability ratio in the cement paste and the volume of foam concrete mix preservation. 2. The possibility of using activating additives, electrolytes to enhance the compressive strength and flexural tensile, frost resistance. 3. Improving product quality category 4. Reduction of thermal conductivity.	Hydrosilicates formation at interaction $mSiO_2 \cdot zH_2O$ c $Ca(OH)_2$ according to the scheme: $nCa(OH)_2 + mSiO_2 \cdot zH_2O \rightarrow$ $\rightarrow nCaO \cdot mSiO_2 \cdot zH_2O$	1. Increased surface hardness. 2. Improving the quality of the foam concrete product category by improving its geometry, which increases the thermal insulation properties of masonry walls of these products. 3. Increased corrosion resistance of foam concrete by binding Ca (OH) 2 in the new formations. 4. Increase adhesion of foam concrete surface.
Iron (III) sol hydroxide	Iron Protein Complex 		Hydroferrites formation at interaction of $Fe(OH)_3$ – sol of ferric hydroxide c $Ca(OH)_2$according to the scheme: $nCa(OH)_2 + mFe(OH)_3 \rightarrow$ $\rightarrow nCaO \cdot mFe_2O_3 \cdot zH_2O$	

proceeds on the surface and inside the generated formations facilitating their congestion. Further growth of the new phase formations is predetermined by the diffusion of hydrated silica molecules through the surface layers of the particles.

Table 1 shows the concepts of the effects produced by colloidal sols on the properties of foam concrete. The suggested foam stabilization process is based on the potential formation of the nanosizedhard phase dispersions in between the foam films and the introduced nanostabilizer that are contained in the non-organic sols and represent complex compounds (complexes) capable of strengthening the foam film thus stabilizing and protecting it in the process of preparing the foam concrete slurry. It seems practicable to select such stabilizing nano-additives as $SiO_2 \cdot nH_2O$ and $Fe(OH)_3$ (nanosilica andnano Fe(III) hydroxide), insofar as those compounds are capable of generating protein complexes in the form of silica- and iron-protein complexes which follows, among other things, from works of R.K. Ayler[3] as well as from fundamental knowledge of chemistry. Such nanosized additives form the hard phase of liquid colloid sols.

2. Method

To prepare the foam, the Foamcemprotein foam agent manufactured by Last on Italian a Spa was used with the specifications as follows:

- Physical form: dark-brown liquid.
- Active ingredient: protein hydrolysate.
- Hydrogen index: pH = 6.5-7.5.
- Density at 21 °C – 1121 kg/m³.
- Viscosity at 21 °C – 1.13 cPs.
- Foam expansion ratio – no less than 13.
- Foam stability – no less than 15 min.

The study investigates the effects produced by sols of hydrated silica and of iron (III) hydroxide obtained by laboratory and by industrial method on the properties of the construction foam and of the foam concrete manufactured on its basis. The principal parameters of silica sols are shown in Table 2.

Legend to Table 2: $\omega^i_{SiO_2}$ – percentage concentration of disperse phase mass of SiO_2 in silica sol; pH – hydrogen index of silica soland S_{sp} – specific area surface of silica sol particles (according to the Sears method).

Hydrated silica sol (H_4SiO_4) was obtained on the basis of liquid soda-ash glass (GOST 13078-81) of 1.46 g/cm³ density with hydrogen index value of pH = 12 applying the ion-exchange technique. This method ensures high purity of the obtained silica sol. Liquid glass was dilated with distilled water to the ratio of 1:20 in terms of mass. The density of the obtained liquid glass solution made 1.014 g/cm³, hydrogen index value pH = 11. The prepared water solution of the liquid glass was put through cation exchanger KU-2-8-ChS (H-form) (GOST 20298-74). As a result, orthosolicic acid sol was obtained with density value of 1.014 g/cm³; hydrogen index value pH = 3–4. Sol of iron (III) hydroxide was obtained by applying the method as follows: 5 ml of 10%-solution of chloride of iron (III) $FeCl_3$was being slowly poured into 100 ml of boiling water. As a result of the following reaction $FeCl_3 + 3H_2O \rightarrow Fe(OH)_3 + 3HCl\uparrow$ iron hydroxide sol has been synthesized possessing brick red color, disperse phase concentration of $\omega_{Fe(OH)_3}$ = 0.33% and hydrogen index value of pH = 2.

Table 2. Main characteristics of the silica acid sols, obtained by the laboratory and industrial processes

Designation	$\omega^i_{SiO_2}$, %	pH	$S_{уд}$, m²/g
Silica acid sols, obtained by the laboratory processes	2.5	3–4	Not measured
KZ-1 "SITEK"	25.6	3.2	120–140
KZ-2 "SITEK"	26.7	6.9	124
KZ-3 "SITEK"	25.6	8.6	143
KZ-TM 30	28.2	10.1	413.4

Experimental slurries were prepared for manufacturing the foam concrete of average density D500. The raw materials were as follows: Starooskolskiy cement PTs 500-D0, high-silica sand (Semiluki District, the Voronezh Region, average grain diameter 0.16 mm, SiO_2 content 98 %), protein-based foam agent. The foam stabilizer was represented by silica sol; the accelerating agent was made of sodium fluoride and chloride of sodium in the amounts of 0.5 % and 5 % of the cement mass accordingly. The complex additive consisted of chloride of sodium in the amount of 5% of the cement mass and of dolomite limestone. With this complex additive the limestone was fed into the slurry as the filling aggregate instead of sand.

The ratios of the raw material components in the initial (benchmark) composition are shown in Table 3.

Table 3. The composition of non-autoclaved of foam concrete average density of D500

Grade of foam concrete according to average density	Material consumption per 1m3 of foam concrete mass			
	Cement, kg	Sand, kg	Foam forming additive l	Water-solid ratio
D 500	320	130	1.7	0.63

The foam concrete was manufactured applying the cutting technology that is most practicable among the existing methods because it makes it possible to manufacture the foam items of any dimensions while simultaneously decreasing the metal consumption rate in the course of production. The strength of the foam materials and their cracking resistance were evaluated starting from the moment of the block cutting and up until the 28th day of normal curing. For the purposes of the investigations the samples used to be cut out of the middle part of the items according to GOST of Russia 10180-78, 7076-99, 21520-89.

3. Results and discussion

In the process of evaluating the physical and mechanical characteristics of the obtained foam concrete items the following observations have been made (Table 4):

- The applied different accelerating agents (electrolytes) do not destruct the stabilized foam.
- The time for gaining the plastic strength required for cutting the foam concrete was reduced by 3-7 hours when the accelerating agents were used.
- The compression strength of the samples with additives after 28 days of curing increases by 50% as compared to the benchmark sample and the bending tensile strength increases by up to 70 %.
- Coefficient of heat conductivity of the samples with additives decreases by 20% as compared to the benchmark.
- Drying shrinkage of the foam concrete items identified according to GOST 21520-89 decreases.
- Amount of the 1st category quality products increases by 23% in cases when the additive is used.

Based on the analysis of the X-ray photograms and thermograms and taking into account the results of the investigations described in other studies[4–15] a conclusion was made that in the activated samples a new phase of hydrated silicate, afwillite, appears and the amount of chemically bound water increases which can explain the higher strength of the samples of the foam concrete blocks and the mechanism of cement hardening with stabilized foam. Besides, insofar as in cases of applying the additives-electrolytes the water-solid ratio decreases due to their plasticizing effect, this could also contribute to improving the strength characteristics of the manufactured items. Then the experiments were carried out applying sol of iron hydroxide for stabilizing the foam in the process of manufacturing the foam concrete blocks with average density of 400, 500 and 600 kg/m^3. The obtained construction and technical properties are consolidated in Table 5.

Table 4. Physical and mechanical, physical and technical characteristics of samples of foam concrete with density of D 500 with various additives

Sample number*	Additive designation	Water-solid ratio	Time of acquiring plastic strength, h	Compressive strength with the age, MPa /%		Tensile strength at bending, MPa /% aged 28 days	Thermal conductivity coefficient, dry condition (W / (m · ° C)) /%	Drying shrinkage, mm / m
				7 days	28 days			
1	Test sample	0.63	17	0.85/100	1.31/100	0.92/100	0.117/100	More than 3
2	NaF	0.58	14	1.04/122	1.60/122	1.28/136	0.113/96.9	Less than 3
3	NaCl	0.58	12	1.2/134	1.8/138	1.46/143	0.106/90.6	
4	Complex additive	0.58	10	1.2/148	1.9/146	1.56/170	0.094/80.3	

* In experiments 2-4, foam was obtained from the stabilized foam solution

Table 5. Physical and mechanical properties of foam concrete samples of medium density of D400-D600 with foam-stabilized sol of iron hydroxide, and various additives, curing accelerators

Grade of foam concrete according to average density	The sol of iron hydroxide,% Fe (OH) 3 of the cement weight	Additives activators		Compressive strength, R_{compr} MPa				Tensile strength in bending, R_{bend}, MPa				Thermal conductivity, λ, W / (m · ° C)
		Designation	% of the cement weight	Age, days				Age, days				
				3	7	14	28	3	7	14	28	
D400	–	–	–	0.4/100	0.6/100	0.7/100	0.8/100	0.29/100	0.35/100	0.41/100	0.45/100	0.100/100
	0.0062	NaF	0.5	0.55/138	0.8/133	0.9/129	1.0/125	0.42/146	0.48/137	0.50/122	0.56/124	0.096/96
		NaCl	5	0.6/150	0.8/133	1.0/143	1.1/138	0.43/148	0.51/146	0.56/137	0.62/138	0.093/93
		Complex additive		0.7/175	0.9/150	1.1/157	1.2/150	0.45/155	0.54/154	0.61/149	0.66/147	0.09/90
D500	–	–	–	0.6/100	0.9/100	1.1/100	1.3/100	0.40/100	0.51/100	0.63/100	0.69/100	0.120/100
	0.0052	NaF	0.5	0.9/150	1.3/144	1.4/127	1.5/115	0.63/158	0.74/145	0.79/125	0.81/117	0.116/97
		NaCl	5	0.9/150	1.4/156	1.5/136	1.6/123	0.64/159	0.79/155	0.87/138	0.92/133	0.114/95
		Complex additive		1.1/183	1.5/167	1.6/145	1.7/131	0.66/165	0.79/155	0.85/135	0.88/128	0.107/89
D600	–	–	–	0.8/100	1.2/100	1.4/100	1.7/100	0.54/100	0.65/100	0.79/100	0.88/100	0.140/100
	0.0043	NaF	0.5	1.3/162	1.8/150	1.9/136	1.9/112	0.86/160	0.96/148	0.98/124	1.07/122	0.136/97
		NaCl	5	1.3/162	1.7/142	1.9/136	2.1/124	0.85/157	0.97/149	1.09/138	1.19/135	0.132/94
		Complex additive		1.4/175	1.9/158	2.0/143	2.2/129	0.87/161	1.03/158	1.12/142	1.15/131	0.132/94

Evaluating physical and chemical characteristics of the laboratory samples of the foam concrete manufactured based on the foam stabilized by sol of iron (III) hydroxide the following facts have been discovered:

- Different accelerators-electrolytes in the slurry do not destroy the stabilized foam.
- Compression strength of the foam concrete samples of average density of D400 with additives after 28 days increases by 25-50 % as compared to the benchmark samples and moves one class higher; the bending tensile strength increases by 24-47 %. Compression strength of the samples of the foam concrete of average density of D500 with additives after 28 days increases by 15-31 % as compared to the benchmark samples and becomes one class higher; the bending tensile strength increases by 17-28 %; compression strength of the samples of the foam concrete of average density of D600 with additives after 28 days increases by 12-29 % as compared to the benchmark samples and the bending tensile strength increases by 22-31 %.
- Coefficient of thermal conductivity with additives decreases by 11% as compared to the benchmark samples.

The data above also show that for the samples of the foam concrete manufactured based on the stabilized foam and applying the complex additive the compression strength after 7 days corresponds to the compression strength of the benchmark samples of the foam concrete after 28 days which can accelerate the whole technological process. The freeze-thaw durability tests were carried out for the samples of the foam concrete of average density of D600 manufactured based on the sol-nanostabilized foam and applying the activating complex additive. The investigation shows that when the complex additive and the sol-stabilized foam are used in combination, the grade of the concrete in terms of its freeze-thaw durability increases from F15 to F35. All investigations were carried out according to GOST 25485-89.

Then the modifications of the foam concrete surface that may occur when applying different types of colloid sols were investigated with the purposes of improving the quality of the manufactured items. The surfaces of the concrete cubes of average density of D400–D600 with the cube edge of 100 mm, upon curing to acquire the required strength of the relevant grade, were treated with sols of hydrated silica and with iron (III) hydroxide at different concentrations and at a flow rate of 2.5 l/m^2. The samples were manufactured using dolomite limestone instead of a part of the filling aggregate. After treatment the samples were cured during 14 days under the normal hardening conditions.

The change in the surface strength of the samples was studied according to the Shore method, applying durometer. The physical and chemical transformations occurring in the surface layer were evaluated and it was evident that the interaction between the introduced nano-additives and the stone pattern results in binding of $Ca(OH)_2$ in the new formations which, according to the existing ideas, are of principal significance for corrosion resistance of the foam concrete items and for the quality of their surfaces. This can improve the durability of the items and of the construction structures manufactured on their basis. It was found that the hardness of the foam concrete surface modified with nano-additives increased by up to 29% in cases of using sols of hydrated silica and iron hydroxide as compared to the benchmark samples[16,17]. The investigations have been carried out with the porous structures of the benchmark samples and with the samples of the foam concrete of average density of D500 manufactured based on stabilized foam with the complex additive. The investigations showed that the dispersive capacity of the pores decreases considerably when the foam stabilizer is present. This can be explained by the fact that the stabilized foam remains more stable in the course of preparing the foam concrete slurry; and in the course of its further curing the fine porous structure of the material is preserved. The results of the investigations applying the methods of mercury porosity measurements in the micro-porous structure of the benchmark sample and in the sample of the foam concrete manufactured based on stabilized foam with the complex additive showed that the role of the stabilizer is reduced to the redistribution of pores[18]. Thereat, the volume of the pores of radius smaller than $1 \cdot 10^2$ Å increases and the volume of the pores of radius larger than $1 \cdot 10^2$ Å decreases; thereat, the total specific surface area of the pores increases two times in the sample with the stabilized foam. This case can demonstrate the effect of the colloid foam stabilizer that is transformed from sol to gel in the system and that makes for increasing the volume of fine and ultra-fine pores; thereat, the number and the total volume of the large and capillary pores decreases. Table 4 shows that introducing sol of hydrated silica results in lower thermal conductivity of the material and its values for samples No. 3 and No. 4 correspond to the relevant values of the foam concrete one class lower in terms of its average density. This can possibly be explained not only by the difference in the porous structure of the samples but also by the nature of silica sol that features amorphous structure which prevents propagation of phonons in the hard phase and also by the low value of thermal conductivity of the mineral filling aggregate (limestone).

The results obtained within the framework of this study in the course of manufacturing foam concrete make it possible to use the advantages as follows:

- Higher stability of the foam concrete slurry that provides opportunities for improving the properties of the foam concrete applying different additives without destroying the porous structure and also by using the slurries of lower density for the purposes, for example, of increasing the height of the grouted thermal insulation layer.
- Wider opportunities for obtaining better dynamic characteristics of the foam concrete slurry due to applying the additives-electrolytes that feature plasticizing properties.
- Improved compression and bending tensile strengths of the foam material and also its lower shrinkage and thermal conductivity.
- Lower production costs of the foam concrete due to lower cement consumption.

Apart from the construction and technical properties, these types of the foam concrete possess geoecological protective features; for example, they are capable of absorbing and retaining ions of hard metals and can be used as geo-antidotes to prevent and to eliminate the pollution caused by the ions of hard metals in soil and turf. Table 6 shows geo ecological and detoxifying properties of the items made of the foam concrete in terms of the ions of hard metals.

Table 6. Geo eco protective properties of samples of building hydrosilicate systems presented by foam concrete with different initial density

The average initial density of foam concrete, kg / m^3	Eliminated contaminant concentration, g / t		
	Cd(II)	Pb(II)	Cu(II)
400	138.68	163.31	60.79
500	107.63	126.74	48.34

4. Conclusion

The investigations above prove that it is possible to control the properties of the foam concrete slurry and the properties of the resulting material, namely, of the foam concrete manufactured with nanostabilizer. Thereat, the study confirms the principal idea that if it is possible to generate the protein complexes at the boundaries of the interactions between the phases in the form of silica sol and protein-containing compounds then the stability of the foam and the properties of the foam material manufactured based on this foam can he improved. The achieved results can be further developed not only based on generating protein complexes of another nature but also on regulating pH medium, controlling temperature modes of curing and also based on more precise specifications of the composition and of the component ratios of the foam concrete slurry.

- To improve the quality of the non-autoclaved foam manufactured items the use of such foam stabilizers as sols of hydrate silica and iron (III) hydrate can be recommended.
- The study demonstrated the possibility of accelerating the curing process of the non-autoclaved foam concrete with accelerators-electrolytes in the presence of the foam stabilizer that does not cause foam destruction but results in better performance characteristics of the foam concrete.
- The undertaken physical and chemical investigations proved deeper degree of hydration of the samples made of the foam with the additives as compared to the benchmark samples.
- The investigations of the porous structure showed the increased dispersion of pores, the increase in their total specific surface area and the redistribution of pores in the samples of the foam concrete items that were made based on the stabilized foam.
- The crushed debris of the foam concrete can be used as geo-antidotes to eliminate soil and turf pollution caused by the ions of hard metals.

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