Foam concrete of increased strength with the thermomodified peat additives

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Abstract. The paper presents the results of research of foam concrete with thermomodified peat additives. The aim of the research was to study the effect of modifying additives on cement stone and foam concrete properties. Peat additives are prepared by heat treatment of peat at 600 °C. Two approaches of obtaining additives are examined: in condition of open air access (TMT-600) and in condition of limited air access (TMT-600-k). Compressive strength of a cement stone with modifiers found to be increased by 28.9–65.2%. Introducing peat modifiers into foam concrete mix leads to increase of compressive strength by 44–57% at 28-day age and heat conductivity of foam concrete decreases by 0.089 W/(m•°C).

1. Introduction
Enhancing production of foam concrete with natural hardening and broadening of its application in construction has significant importance due to the demand for energy efficiency and necessity of energy intensity reduction while walling materials production [1]. Performance of foam concrete can be enhanced by ensuring the required strength while reducing thermal conductivity of material when selecting raw materials, composition design, preparation of raw mixture, products modeling that can be achieved by maximum saturation of the material’s volume with air bubbles. This can be reached by application of foam with the bubbles of size ensuring tight packaging or by saturation of sand-cement partitions with microporous disperse agents increasing the strength of cement stone [2]. Problem can be solved by introducing porous organic-mineral active modifiers into cement-sand mixture. Previous research resulted in development of method for production of modifiers based on peat and examined their influence on the properties of cement composite materials [3].

Specific feature of raw material base of many Russian regions is the presence of large reserves of peat. Composition of peat is various and represented by numerous functional groups, including both organic and mineral compounds, which provide different ways of its processing to obtain components of required composition and properties for the production of building materials of different purposes [4, 5].

The main purpose of current research is the development of formulations and scientific substantiation of technological methods for thermomodified peat additives and foam concrete of increased strength with the additives production.
2. Materials and methods

For the study of foam concrete following initial materials were used:
- Portland cement from "Topkinsky Cement" plant, ЦЕМ I 42,5Н type - cement complies with requirements of All Union State Standard (GOST) 31108-2003;
- Silica sand from Kudrovskoe field, size modulus 1.44 - sand complies with requirements of Russian National State Standard (GOST) 8736-93;
- Foaming agent Benoteh PB-C;
- Additives based on peat: TMT-600 and TMT-600-k.

Peat organic-mineral additives TMT-600 and TMT-600-k were obtained by heat treatment of peat of low type at 600 °C for 2 - 4 hours. After the heat treatment the resulting material was ground up in a planetary mill to the specific surface area 161 m²/kg. Preparation of foam concrete mixture was carried out by one-step method in a laboratory foam concrete mixer with volume of 10 liters. A mixture of sand, cement and water (80 %) was stirred for 2 minute. Then the foaming agent was injected into the mixer with 20% of mixing water and the mixture was stirred for an additional 3 minute. Ready foam concrete mixture was poured into metal molds 10x10x10 cm. Formed foam concrete samples were kept in the standard wet conditions for testing. Testing and evaluation of the quality of foam concrete were carried out according to the requirements of All Union State Standard (GOST) 25485-89.

A hydraulic press was used to determine the compressive strength. IR of spectroscopic studies of cement stone samples with addition of peat modifiers were performed on FT-IR spectrometer Nicolet 5700, and electron microscopic studies were carried out on the microscope SEM SamScan-4. Electron microscopic studies of foam concrete samples were carried out on the microscope Philips SEM 515.

3. Results

Technology for the production of peat modifiers was earlier developed by the authors of current article. It is established that during peat thermal processing in open air conditions at 600 °C (TMT-600) organic-mineral complexes in the form of fibers are formed. These complexes provide the effect of micro-reinforcement of cement stone structure. The maximum increase of compressive strength of cement stone (to 28.9%) is observed when the content of peat modifiers is 6 % by mass [6].

In order to improve the efficiency of organic-mineral additive method for production of peat modifier it was investigated on laboratory installation in conditions of limited air access. The pre-drying peat was heated in the sealed reactor to 600 °C for 2 - 4 hours. The resulting product was ground up in a planetary mill to the specific surface area 161 m²/kg. The additives were introduced into the cement in an amount of 0.5% of cement weight. As a result of reactions of hydrolysis, hydration, coordinate restructuring of organic compounds, changes of correlation between the functional groups (amino-phenol, carboxylic et al.) both quantitative and qualitative nature take place, nanoscale structures of fulleroid type with high surface energy are formed. It determines activity of the synthesized additive TMT-600 towards cement.
Figure 1. Strength characteristics of cement stone samples modified by additives TMT-600 and TMT-600-k.

Figure 1 presents the results of research of strength characteristics of cement stone modified by peat additives obtained in various ways. It is established that the effect of the compressive strength improvement of the cement stone by applying additives TMT-600-k is higher than by applying similar additives obtained in open air condition. Thus, at a content the additive TMT-600 in an amount of 6 % of the cement mass compressive strength increased by 28.9%, while at a content of the additive TMT-600-k of 0.5 % strength of cement stone increased by 65.2%.

To assess the impact of peat additives TMT-600 and TMT-600-k on the foam concrete strength in different periods of hardening, composition of foam concrete mix previously developed for industrial applications was used (per 1 m$^3$): 416 kg of cement; 265 kg of sand; 0.9 kg foaming agent, and 230 L of water. Peat modifiers are introduced in the amount of 25 kg. When introducing additives TMT-600 and TMT-600-k in foam concrete mixture compressive strength of foam concrete increased by 45-56 % in 3-days age, by 33-46% in 7-days age, and by 44-57 % in 28-days age (Figure 2).

Figure 2. Changing of the strength of foam concrete modified by additives.

For the improvement of energy efficiency of the foam concrete applied to arrange thermal protective enclosing structures of buildings structural porosity and thermal conductivity are essential. The research results of the effect of additives TMT-600 and TMT-600-k on the foam concrete porosity are shown in Figure 3.
The results of the data analysis showed that the total porosity of the foam concrete modified by peat additives TMT-600 and TMT-600-k increased up to 12%, compared to basic samples without additives. At the same time the samples with peat additives are characterized by prevalence of closed porosity of 27%. Thermal conductivity of modified foam concrete with peat additives decreased by 14% with insignificant decrease of average density (Table 1).

**Table 1.** Influence of additives TMT-600 and TMT-600-k on the foam concrete properties.

| Composition                               | Average density, kg/m³ | Thermal conductivity, W/mK |
|-------------------------------------------|------------------------|---------------------------|
| Basic sample                              | 757                    | 0.105                     |
| Foam concrete sample with TMT-600         | 733                    | 0.092                     |
| Foam concrete sample with TMT-600-k       | 730                    | 0.089                     |

**4. Discussion**

The study results showed that peat modifiers significantly accelerate the process of structure formation of cement stone and porous cement-sand mortar of foam concrete. Thus, at a lower dose (0.5%) additive TMT-600-k provides increase of foam concrete strength at 28-days age almost two times higher than additive TMT-600 at a dosage of 6%. To explain the structure formation mechanism of cement stone with peat additives the IR spectroscopic studies of cement samples were conducted at 28-days of hardening (Figure 4.).
On the IR spectrum following absorption bands were identified:
- bands in the range of (3500-3400) cm\(^{-1}\), due to stretching vibrations of the free group OH in the adsorbed water;
- shift of the absorption bands of OH groups in the range of (3940 – 3800) cm\(^{-1}\). Offset band of OH groups is sensitive to the organic compounds adsorption and the shift, broadening and an increase of the integrated intensity of the surface OH groups band is the spectral manifestation of the interaction of molecules with minerals active hydroxyl groups, which is carried out through the formation of new hydrogen bonds;
- bands at 3400 and 3258 cm\(^{-1}\), should be attributed to the asymmetric valent and the first overtone of the bending vibration of the molecules adsorbed water.

According to the analysis, results of IR spectra of the cement stone with additives and of the base cement stone at the age of 28-days hardening are identical. The results of IR spectroscopic analysis indicated that the peat additives are actively involved in the process of cement stone structure formation only on early terms of hardening.

In the electron micrographs of the cement stone with additives TMT-600-k (Figure 5) a significant amount of fibrous framework structures was identified, i.e. interwoven fibers of mineral or organic-
mineral composition thickness from 552 nm to 10 microns and a length of up to 100 microns. The fibers have randomly oriented structure and it is likely that their presence in the cement matrix provides a reinforcing effect, which leads to an increase in strength. Fibrous inclusions have a homogeneous dense border with cement stone. Thus, the introduction of additives TMT-600 and TMT-600-k into the cement matrix ensures reinforcing and structuring effect in cement stone.

According to the study results of the foam concrete porous structure with an average density of D800 both the base sample (Figure 6 a) and sample with the addition of TMT-600 (Figure 6 b) the influence of peat additives on the pore structure of foam concrete was established by means of electron microscopy method. Foam concrete with additives predominantly has closed pores unified in size (mainly 0.05 mm) and evenly distributed over the volume. General and closed porosity has increased by 27 %. Decrease of pore size contributes to reduction of foam concrete thermal conductivity from 0.105 W/(m∙°C) up to 0.09 W/(m∙°C), i.e. by 14 %. The picture of the basic sample shows that the pores are through; they arranged randomly which reduces material thermal insulation properties. When introducing porous active mineral additives TMT-600 and TMT-600-k in cement matrix, effect of filling sand-cement walls with micropores is observed while increasing the cement stone strength.

![Figure 6. Electron micrographs of foam concrete: a) base sample; b) modified sample with additive TMT-600.](image)

Thus, the introduction of peat additive into foam concrete mixture allows increasing foam concrete strength by 44 – 57 %, increasing porosity by 27 %, and decreasing thermal conductivity by 14 %.

5. Conclusion
By thermal treatment of peat at 600 °C in open air conditions or in conditions with limited air access effective additive for modifying structural cementitious mixtures was obtained.

Introduction of peat modifiers into foam concrete mix leads to improved quality of porous structure and speeds up the structure formation process that enhances the grade strength and reduces the thermal conductivity of foam concrete.

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