Electroactivation of Foam Concrete for Buildings and Structures with Improved Constructive and Energy Efficient Characteristics

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Abstract. The paper describes a method for sealing the material of interporal partitions in order to eliminate capillary porosity and increase the area of interparticle phase contacts by applying an alternating electric field to the formed foam concrete mixture. Based on the results of these tests, a positive tendency has been found to increase the efficiency of the electro activation during the short-term exposure of the alternating electric field to the foam concrete mixture. It was found that with the increase in the dispersion of the aggregate, the ratio of B / W naturally increases, which makes it possible to achieve the required viscosity of the foam concrete mixture, therefore, in order to obtain the required density of foam concrete, it was necessary to increase not only the flow rate of the mixing water, but also the foam agent dosage. It was found, that the electric activation of foam concrete mixtures increases constructive characteristics of foam concrete with various kinds of cement; its efficiency is higher for a foam concrete based on a more coarsely dispersed Portland cement. The difference in the results is due to the fact that in highly dispersed cement, even with a short hydration, a more viscous cement gel is created, which reduces the efficiency of the electric activation.

1. Introduction

Controlling the formation of structure in foam concrete is one of the key ways to improve the quality, and first of all the physico-mechanical properties of foam concrete. As it is known, the strength of cellular concrete greatly depends on the physico-mechanical properties of the interporal partition material, in particular its density [1]. However, in real materials solid particles are usually not densely packed due to their angularity and roughness.

In heavy-weight concrete technology, structure is usually condensed by mechanical vibrations, whereby more orderly arrangement of aggregate grains is caused by the effect of gravitational forces that occurs after the thixotropic dilution of the cement slurry. Given the grain size of heavy-weight concretes, their structure is usually improved by vibrations within a 50 to 100 Hz industrial frequency range. However, particles of the inert components of foam concrete are sized < 1 mm, which requires a 100x or even higher vibration frequency. At such frequencies, vibrations are quickly attenuated in
viscous media, while more powerful vibrations cause undesirable alterations in the macrostructure of foam concrete, a fact recorded in several papers.

One of the most efficient yet under-studied ways to affect the processes occurring at the phase interfaces in concrete consists in using electrophysical methods.

2. Experimental program and research results

The authors believe an efficient way to condense the interpore partition material to eliminate its capillary porosity and increase the area of inter-particle phase contacts consists in exposing the formed foam concrete to an alternating electric field. As it is known, the particles of cement and mineral aggregate, e.g. quartz sand, bear a surface electrical charge [2, 3].

In the initial period of the hydration of cement particles in the mixture when coagulation inter-particle contacts emerge, charged solid particles in the liquid medium are in an balanced equilibrium state, mostly fixed in the positions of the far energy minimum [4]. As a result of the periodic mechanical effect of the alternating electric field, these particles and their solvation shells can be caused to oscillate. Thus, accidental weak structural links in the filled cement paste will be destroyed. This will cause a thixotropic liquefaction in micro-volumes, which will facilitate a more dense packing of inert-component particles in the interpore partition material. The advantage of this method is that the oscillation energy is applied directly to the aggregate grains without affecting the macropores in the foam concrete structure.

Consider the theoretical basis behind this proposed technological solution. Let foam concrete be placed between flat electrodes at the distance $l$ from each other, and let an alternating electric voltage be applied to them

$$U = U_0 \cos \omega t$$

(1)

Let the aggregate grain charge equal $q$ and the aggregate grain mass equal $m$. Thus, in the alternating electric field we observe

$$E = E_0 \cos \omega t$$

(2)

where $E_0 = U_0 / l$ is the amplitude of the electric field in the bulk material.

The grain is exposed to the force

$$F(t) = F_0 \cos \omega t$$

(3)

where $F_0 = qE_0$.

As the grain is located in a low-viscosity medium and is surrounded by other grains, it is exposed to the quasi-elastic force

$$F_y = kx$$

(4)

where $x$ is the displacement of the particle from the equilibrium position, and the resistance force

$$F_c = r\nu$$

(5)

where $\nu$ is the speed of the particle, and $r$ is the medium resistance factor. In the steady state, the aggregate grain will make forced harmonic oscillations with the amplitude:

$$A(\omega) = \frac{q_0E_0}{m \sqrt{(\omega_0^2-\omega^2) + \frac{r^2\omega^4}{m^2}}}$$

(6)

Sustaining such forced oscillations in a system with viscous friction requires spending a certain amount of power [5], which in this case is absorbed by foam concrete upon electric activation. It can be referred to as the loss power, as it is spent to overcome the medium resistance forces as aggregate particles are oscillating, and thus eventually turns into heat. Average loss power in foam concrete volume $V$ with the aggregate particle concentration $n$:
\[ P_n = \frac{n r q^2 u_0 \omega^2 V}{2 m^2 i^2 \left( \omega_0^2 - \omega^2 \right) + \frac{r^2 \omega^2}{m^2}} \] (7)

This power equals the electric power consumed from the AC voltage generator:

\[ P_{\text{el}} = \frac{1}{2} U_0 I_{\text{a}0} \] (8)

where \( I_{\text{a}0} \) is the amplitude of the active component of the current flowing through the concrete mix. Therefore:

\[ I_{\text{a}0} = \frac{n r q^2 \omega^2 V U_0}{m^2 i^2 \left( \omega_0^2 - \omega^2 \right) + \frac{r^2 \omega^2}{m^2}} \] (9)

As can be seen, the foam-concrete absorption of energy is resonant in nature, whereas the dependence of \( I_{\text{a}0} \) on the circular frequency \( \omega \) must be maximized at \( \omega \approx \omega_0 \). Apparently, electric activation is the most efficient in this case.

To prove their hypothesis, the researchers used a special measuring cell with cylindrical coaxial electrodes, see Figure 1.

![Figure 1. Measuring cell with cylindrical electrodes, connected to a generator and a multimeter](image)

The cell was filled with the prepared foam concrete and connected to a G3-118 low-frequency generator. The amperage in the sensor circuit was measured by a B7-21A multimeter. The experiments to record the frequencies in the measuring cell with foam concrete did not last more than 10 to 15 minutes; as was found out, the rheological properties and the electrical resistance of the mixture would remain virtually unchanged over that timeframe.

Foam concrete was mixed in a turbulent mixer in a single pass. For the experiments, we used additive-free M400 Portland cement; the aggregates in user were ordinary sand with a fineness module \( M_{\text{fn}} = 0.83 \) plus sands of specific fractions: 315-140 \( \mu m \) and 140-70 \( \mu m \); we also used Arekom-4 foaming agent (0.3% of the mass of the cement). The water-solids ratio (W/S) in the mixtures was 0.4.

Figure 2 shows the dependency of the effective total current value \( L (a) \) and its component \( I_{\omega} (b) \) on the applied-voltage frequency \( \omega \). The current value \( I_{\omega} \) that determines the amount of electric power received from the generator to sustain forced oscillations of the aggregate particles was found as

\[ I_{\omega} = I - I_{\text{ltc}} \] (10)
where $I_{ltc}$ is the magnitude of the let-through conductivity current found by approximating the curves of $I(\omega)$ to the frequency $\omega \to 0$.

Figure 2. AC voltage frequency dependency of the total current (a) and the current describing the loss of oscillation energy (b) through the foam concrete mixtures with various aggregates and additives

Curves 1 to 3 correspond to foam concretes where the aggregates used were sand of different dispersions: 1 is for the ordinary sand with $M_{fn} = 0.83$; 2 is for the same sand with a 315-140 $\mu$m fraction, and 3 is for the same sand with a 140-70 $\mu$m fraction. As can be seen from the figure, the absorption of energy by foam concrete is resonant in nature, which agrees with the hypothesis. Although each curve is derived from the superposition of such curves for each individual grain size, the maximum position of curves 1 to 3 apparently corresponds to the weighted-average grain size in the aggregate fraction and naturally shifts towards higher frequencies. Curve 4 corresponds to a foam concrete mixture where 140-70 $\mu$m sand was supplemented with C-3 superplasticizer. As can be seen from the figure, reduced viscosity of the cement-sand mortar increases the current value $I_\omega$ at the curve maximum, which apparently is due to a greater number of mineral particles involved in the oscillatory motion.

To produce sample cubes with a 7-cm edge, the prepared foam concrete was poured into a dielectric mold with flat metal electrodes located laterally in the mold opposite to each other, see Figure 3. Foam concrete was exposed to electric field immediately after pouring. To that end, the electrodes were connected to a G3-109 alternating electric voltage generator, see Figure 4.
3. Conclusion

Analysis of these results proved the treatment of foam concrete with alternating electric field an efficient method. Treated foam concrete was less dense as short-term electric activation caused the interpore partition material to condense, which increased the pore volume without compromising the integrity of the material structure. These changes in the foam-concrete structure resulted in a greater density compared to controls, whereas the structural quality coefficient of the activated foam concrete was greater than that of its non-activated counterpart.

Similar experiments were carried out with mixtures containing sands of another dispersion. Tests showed that treating foam concretes with coarse aggregates, or more viscous mixtures requires a higher voltage of the electric field.

These experiments show a positive trend, i.e. improvements in the efficiency of electric activation when foam concrete is subjected to an alternating electric field for a short time.

The type, content, and grading of the aggregate is important for the structure formation of foam concrete. Literature does not provide any precise data on the optimal grain size of aggregates for use in foam concrete. Mixed and small fractions are preferred.

It has been found out that greater aggregate dispersion naturally increases the water-soilds ratio (W/S), allowing to achieve the desired foam concrete viscosity; therefore, to attain the desired foam concrete density, one has not only to spend more mixing water, but also to increase the foaming agent dosage.

It has been found out that the electric activation of foam concrete improves the structural properties of foam concrete for various types of cements; it is more efficient for foam concretes based on a more coarse Portland cement. The difference in results is due to a more viscous cement gel being produced in finely dispersed cement even in case of short hydration; the gel makes electric activation less efficient.

In all the experiments, the physico-mechanical properties of foam concrete produced from electric field-treated mixtures were generally better; activated materials were proven more design- and energy-efficient for buildings and structures.

References

[1] Gorlov Yu P, Merkin A P and Ustenko A A 1980 Technology of Thermal Insulation Materials (Moscow: Stroyizdat) 399 p
[2] Bazhenov Yu M 2007 Concrete Technology (Moscow: ASV) 528 p
[3] Ajler R 1982 Chemistry of Silica Part 2, ed V P Pryanishnikov (Moscow: Mir) 712 p
[4] Shakhovala L D 2010 Technology of Foam Concrete. Theory and Practice. Monograph (Moscow: Association of Construction Universities) 248 p
[5] Aleshkevich V A, Dedenko L G and Karavaev V A 2001 Oscillations and Waves (Moscow: Publishing house of the Physical Faculty of Moscow State University) 147 p
[6] Rebinder P A 1978 Superficial Phenomena in Dispersed Systems: Colloid Chemistry. Selected Works (Moscow: Nauka) 368 p
[7] Rebinder P A Physical and Chemical Basics of Foam Concrete Production Proceedings of the USSR Academy of Sciences 4 362–370
[8] Prishhepa L T 1964 Effect of the Electric Field on the Crystallization Parameters of the Substance. Mechanism and Kinetics of Crystallization (Minsk: Science and Technology) pp 282–290
[9] Proshin A P, Eremkin A I, Beregovoj V A and Korolev E V 2002 Cellular Concrete for Thermal Insulation of the Building Envelope and Communications Engineering Construction Materials 3 14–15
[10] Pshenichnyj G N 2005 Effect of Cyclic Vibration on the Properties of Non-Autoclave Foam Concrete Construction Materials 5 10–11
[11] Tkachenko G A, Izmalkova E V and Mal'tsev N V 2004 Foam Concrete in Natural Quartz Sands Materials of the Int. Conf. "Construction-2004" (Rostov-on-Don: Rostov State University of Civil Engineering) pp 47–48
[12] Scherban E M, Tkachenko G A, Goltsov Yu I and Stelmakh S A 2012 About the Influence of Treatment of Foam Concrete Mixture by Variable Electric Field on the Properties of Foam Concrete Modern Problems of Science and Education (2012) 1
[13] Goltsov Yu I, Tkachenko G A, Grekov R V, Scherban' E M and Stel'makh S A 2010 Electrovibration treatment of Foam Concrete Mix. Theoretical Basics and Technological Aspects Materials of the Int. Scientific and Practical Conf.: "Construction - 2010" (Rostov-on-Don) (Rostov-on-Don: Rostov State University of Civil Engineering) pp 11–14
[14] Scherban E M, Goltsov Yu I, Tkachenko G A and Stelmakh S A 2012 Prescribed Processing Factors and Their Function in Generation of the Characteristics of Foam Concretes, Obtained from Mixtures, Treated by Variable Electric Field Engineering Journal of Don (2012) 3
[15] Stel'makh S A, Scherban' E M, Khalyushiev A K, Kholodnyak M G, Nazhuev M P and Galkin Yu V 2017 The Influence of Technological Factors on the Properties of Non-Autoclaved Aerated Concrete Engineering Journal of Don (2017) 2
[16] Shuyskiy A I, Stel'makh S A, Scherban' E M, Khalyushiev A K, Kholodnyak M G and Shatalov A V 2017 Effect of a Structuring Additive on the Physical and Mechanical Properties of Non-Autoclaved Aerated Concrete Engineering Journal of Don (2017) 2
[17] Scherban E M, Stelmakh S A, Goltsov Yu I and Yavruyan Kh S 2013 Electro-Activation Efficiency of Foam Concrete Mixtures Engineering Journal of Don (2013) 4
[18] Scherban E M, Stelmakh S A, Serebrjanaya I A, Goltsov Yu I and Yavruyan Kh S 2013 Optimization of Factors Affecting the Efficiency of Treatment of Foam Concrete Mixtures by the Action of an Alternating Electric Field Engineering Journal of Don (2013) 4