Influence of electrified surface of cementitious materials on structure formation of hardened cement paste

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Abstract. To provide high strength and durability of concrete it is necessary to study the influence of physical and chemical and mechanical principles of dispersed cementitious systems. The experimental bench was developed to study the influence of electrified surface of cementitious materials on structure formation of hardened cement paste. The test bench allows accelerating the processes of dissolution of cementing materials in water due to influence of electric discharge on their surface. Cement activation with high-voltage corona discharge when AC current is applied allows increasing the ultimate compressive strength of hardened cement paste by 46% at the age of one day and by 20% at the age of 28 days.

1. Introduction
High-voltage discharge as a mean of obtaining plasma state of matter is widely used in science and engineering. High-voltage discharge is considered to be the one occurring in gas under the action of AC or DC current applied to electrodes.

Construction engineering allows not only to manufacture products but also to study physical and chemical, mechanical principles of dispersed cementitious systems in order to get the required material properties, find the most effective and economic production processes of obtaining mortar and concrete.

Composition and product type of cement hydration can be controlled at nano-level by composing the structure inside the molecules. The system classifying chemical reactions is built on transfer of electrons, electron pair, proton and atomic molecular particles. It is possible to obtain new chemical compounds of different and necessary basic capacity with different content of hydrated water, of different size and form of crystals thus providing the required strength, frost resistance and water resistance of dispersed cementitious systems.

The main strength of cement paste is provided by crystals and crystal joints that form the hydrated new growths, their sizes being within the range of 10…17 nm. The hydration products less than 10 nm in size are placed in the spaces between crystals, thus combining all the new growths in a single solid body.

P.A. Rebinder [10] noted that all the ways to enhance the production processes in condensed dispersed systems are based on controlling the properties of structure that was formed by the system.
particles. The basic parameters describing structure of system is total potential energy of hydration defined as:

\[
E = E_0 + E_{pol} + E_{disp} + E_{end} + E_{rep} + E_{solv} + E_{ext},
\]

where \(E_0\) – ion-dipole interaction energy; \(E_{pol}\) – polarization energy; \(E_{disp}\) – dispersion-interaction energy; \(E_{end}\) – endo-effect; \(E_{rep}\) – dipole-ion repulsive energy; \(E_{solv}\) – solvent polarization energy; \(E_{ext}\) – interaction energy of solvent molecules (distant hydration) and the surrounding water.

According to Sychev’s [11] classification, the hydration process is divided into a number of simple processes: adsorption at the active centers of water molecules, excitation of active centers, dissociation of the water molecule, formation of active groups, surface bond breaking, release of structural components (\(\text{Ca}^{2+}, \text{SiO}^{4+}\)), polymerization of [\(\text{SiO}^{4+}\)] groups into dimers, binding of \(\text{Ca}^{2+}\) ions with dimer, trimeric anionic grouping, formation of hydrate nucleus with high-surface area, adsorption of water on the surface of hydrates, excitation of centers with adsorption energy, water molecules dissociation and formation of \(\text{H}^+\) and \(\text{OH}^-\) active groups, transfer of protons and \(\text{OH}\) groups through the layer of new growths into reaction zone, catalyzation of the process of breaking bond \(\text{Si–O–Ca}\) on a new surface of minerals under the layer of new-growths by means of sharp increase in active groups concentration as a result of formation of fine-grained hydrates and increase in adsorption surface where the water molecules dissociate into protons and \(\text{OH}\) groups; formation of nucleus of hydrating phases in Taylor layer (Figure 1).

![Figure 1. Polarization of dielectrics in the external electric field of the cementitious material surface.](image)

The connection between strength, the average adhesive power in the contact and the number of contacts is defined by the known correlation by Rebinder and Schukin:

\[
P_m = a_1 \overline{F}_c n^{2/3} = a_2 \overline{F}_c \varphi S^2 = a_3 \overline{F}_c \varphi R^{-2}
\]

where \(P_m\) – yield value; \(\overline{F}_c\) – the average adhesive power in contact; \(n\) – number of contacts per unit volume; \(\varphi\) – dispersed system; \(S\) – specific surface area with the size \(R\); \(a_1, a_2, a_3\) – constants.

2. Research design and results

At the Department “Construction Engineering Technology” of Tomsk State University of Architecture and Building (TSUAB) the research is held to establish the influence patterns of high-voltage discharge both on the cement and on cement suspension [1–7]. First of all high-voltage discharge allows to accelerate the processes of cementing agents dissolution in water by means of influence of electric discharges on their surfaces, i.e. the more intensive dissolution of cement particles in water occurs.

\[
\frac{RT}{V_m} \ln \alpha = \frac{2\sigma}{r} - \frac{q^4}{8\pi \varepsilon r^3},
\]

where \(R\) – universal gas constant; \(T\) – absolute temperature; \(V_m = M/\gamma\) – mole extent; \(M\) – molecular weight; \(\gamma\) – relative weight of the dissolving phase; \(\alpha = c/c\infty\) – oversaturation degree; \(\sigma\) – the specific
free surface energy; $r$ – radius of equilibrium particles (it is suggested that the particles have a round shape); $q$ – electric discharge of particle with radius $r$; $\varepsilon$ – dielectric constant of solvent.

Implementation of ozone technologies requires developing ozone synthesis systems, one of the ways being barrier-surface discharge. Barrier-surface discharge differs from barrier discharge by dynamic capacity due to treatment of dielectric with plasma discharge.

**Figure 2.** Barrier-surface discharge layout: 1-dielectric; 2-corona electrode; 3-inductive electrode.

Barrier-surface discharge works as follows: in case of placing wire or metal strip 2 on one side of dielectric plate 1 (Figure 2), and covering the other side of dielectric with conductive material 3 and provide AC or pulsing voltage between the electrodes, the current will flow in circuit. At low voltages it is insignificant displacement current as the dielectric is a condenser. With increase of definite voltage the discharge spreads over the surface of dielectric from the corona electrode.

To study the influence of electrified surface of cementitious material on structure formation of hardened cement paste the experimental bench was developed. The test bench consists of: autotransformer (T1); step-up transformer (T2); discharge node (Figure 3).

**Figure 3.** Test bench layout.

Hardened cement paste prepared on mineral aggregates electrified in ionized air environment under appropriate process conditions has better physical and mechanical properties, which was confirmed by the performed studies. Therefore cement paste has better performance properties as compared with the one prepared by traditional technology that was also confirmed by a number of studies.

The samples under study were as follows: water-cement ratio from 0.3 to 0.4; cement mark ПЦ400. Cement was subjected to activation in high-voltage corona discharge during 5, 10, 15, 20, 25 seconds. The samples were incubated during 28 days in normal hardening conditions.

Resulting from the experimental studies on the influence of electrified surface of cementitious materials on the structure formation of hardened cement paste the following data was obtained (Figure 4).
Figure 4. Compressive strength of hardened cement paste

3. Conclusions
Cement activation with high-voltage corona discharge when AC current is applied allows increasing ultimate compressive strength of hardened cement paste per 46% at the age of one day, and per 20% at the age of 28 days.

The universal nature of the developed test bench includes: application as a part of almost any production technology of any items and structures with the use of cement; low energy consumption; possibility of combined use with other cement activation technologies; using for activation of any cementitious materials; faster activation time compared to other activation technologies; no defects while cement activation.

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