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On the Physicochemical Nature of the Creep of Autoclaved Aerated Concrete with an Allowance for Carbonization

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***Abstract* – The article touches upon the issue of the assessment of the effect of atmospheric carbon dioxide on the development of creep deformations in autoclaved aerated concrete. The authors carried out the extensive experimental and theoretical studies of creep deformation and its reversibility on prisms with various degrees of carbonization in order to determine the physicochemical nature of the creep of aerated concrete during carbonization. As a result, it was found that the main reason for the increase in creep and reduction of its reversibility for aerated concrete, taking into account its carbonization factor, is the fact that the content of the gel-like part of silica acid increases and the volume of the crystalline part of the solid phase changes. There is an increase in its absolute specific surface; microdamages in the structure of concrete are growing and they are associated with the conversion of hydrated calcium silicate to calcium carbonate.**

Keywords* – *aerated concrete; carbonization; creep deformation and its reversibility; degree of carbonization; creep nature.

I. Introduction

Detailed reviews of concrete creep studies and interpretations of its physical nature are given in the works of such Russian scientists as N.Kh. Arutiunian [1], S.V. Aleksandrovskii [2–5], K.S. Karapetian [6], I.I. Ulitskii [7], Z.N. Tsilosani [8], A.E. Sheikin [9], Tamrazian A.G., Yesaian S.G. [10], and foreign researchers Hansen [11], Lermith [12], and others.

The first hypothesis about the physical nature of creep belongs to E. Freyssinet. According his opinion, the creep of concrete is mainly reasoned by the shrinkage under the action of capillary forces.

R. Lermith [12] sees the cause of the long-term deformation of concrete in mechanical viscous extrusion under the load of liquid moisture from the structure of a cement stone.

Hansen [11] takes as a basis the viscous flow of particles (crystals) connected to each other by coagulation contacts as the main cause of creep.

A.E. Sheikin [9] proposes a hypothesis about the physical nature of concrete creep, which is based on the basic principles of the fluctuation theory of strength of academician S.N. Zhurkov, as well as molecular-kinetic ideas about the mechanism of destruction of coagulation contacts. According to the hypothesis A.E. Sheykina creep of concrete is a consequence of the viscous flow in time under the load of the gel - one of the structural components of the cement stone.

A group of scientists (D. Gliuklikh, O. Ya. Berg, G. Riush) associates the creep of concrete with the inevitable continuous occurrence and development of microcracks and other microcracks caused by the increase in pressure level [2].

According to I.N. Akhverdov [27], the physical nature of creep lies in the ability of crystal-hydrate formations to move mutually across the layers of water between them.

A.V. Volzhenskii believes that linear creep, being a consequence of the elastic-viscous flow of cement stone, also depends on the specific surface of its new formations [28].

There are opinions that the creep of concrete is the result of a number of reasons in their various combinations. For example, K.S. Karapetian [6] believes that at low pressures, concrete creep is a consequence of the viscosity of the gel component of cement stone and capillarity. At high pressures, apart from these reasons, the formation and development of microcracks in concrete already play a significant role. The relative role of these factors in the creep process of concrete depends on a number of factors: the level of pressure, the age of concrete, the temperature and humidity of the external environment.

S.V. Aleksandrovskii, A.A. Gvozdev, I.E. Prokopovich have the same opinion but they also consider it important to change the moisture content of the gel during its drying, and especially because of the mechanical effect of a long-lasting load [2].

Z.N. Tsilosani believes that concrete creep is mainly reasoned by the gradual emergence and development of cracks and breaks in the crystallization structure of concrete and intercrystalline viscous flow. The remaining factors, in his opinion, are of concomitant nature [8].

In the field of creep of autoclaved aerated concrete, the studies of following domestic scientists are known: S.V. Alexandrovskii, B.P. Danilov, E.Y. Bagrii, V.Ya. Bagrii [3–5], V.I. Skatynski and Yu.V. Krumelis [13-14], N.I. Levin, M.Ya. Krivitskii, A.P. Scastnii, A.S. Nolde-Starchenko [15,16], ZH.B. Solovei, V.A. Pinsker [17], LA Rannamiagi [18], A.D. Gumuliauskas and K.A. Puodzhiukinas [19] and the works of foreign authors L. Beres [20], F. Kruml [21], J. Khaust, F. Alou and F. Vitmann [22].

According to S.V. Aleksandrovskii, V.I. Skatynskii and N.I. Levin [3–5,13–16], the main cause of the development of linear creep deformation of autoclaved aerated concrete (without taking into account the carbonization factor) is the formation of microcracks in the body of concrete under the action of prolonged load.

The influence of the carbonization of ordinary concretes for their creep was noted in the works of foreign researchers Alexandre and Parrot [23, 24].

Alexandre [23] notes that preliminary carbonization in a carbon dioxide environment (70% CO_2) of samples from concrete of ordinary hardening reduces creep deformations by a factor of 3–4 against samples that are carbonized in air. In his opinion, the decrease in the creep deformation of concrete samples preliminarily carbonized in a carbon dioxide environment occurs as a result of the formation of a crust of denser and stronger carbonate concrete on the sample surface.

L.I. Parrot [24] investigated the creep of ordinary hardening cement stone during carbonization by atmospheric carbon dioxide of 1.25x1.25x11 cm samples under load equal to 10% of their strength.

According to chemical analysis data, the content of CO_2 in samples kept in a normal atmosphere was 5% by weight, against 0.08% for samples protected from atmospheric carbon dioxide.

The increase in creep deformation of specimens by 70% when they are carbonized for seven weeks Parrot relates to chemical erosion of stressed cement hydrates. This leads, in his opinion, to the loss of the bearing capacity of the cement stone as a result of the conversion of hydrated calcium silicate to calcium carbonate.

A.D. Gumuliauskas and K.A. Puodzhiukinas [19] studied the effect of carbonization on the creep of autoclaved aerated concrete under tension. Creep was determined on samples of 10x16x100 cm with their simultaneous carbonization with 100% carbon dioxide. Simultaneously, isolated samples were tested for comparison. The value of creep of carbonized concrete was 10–15 times higher than the value of non-carbonized concrete. The authors note that the strength and modulus of tensile elasticity decreased respectively by 50–60 and 35–40% due to carbonization.

II. Methods and materials

In order to identify the mechanism of the effect of the carbonization factor on the development of creep deformations and the degree of their reversibility for autoclaved cellular concrete, we studied prism specimens 10x10x40 cm in size from gas-foam concrete with a density of 600 kg / m3 [25,26].

Five series of samples were tested, one of which was non-carbonated samples, and four with carbonization degrees equal to 38, 45, 59 and 66%, respectively, achieved under the action of 10% carbon dioxide. Non-carbonated concrete had an initial carbonization degree of 13%, and fully carbonized concrete had 66%.

Each series consisted of 15 isolated twin samples with the same degree of carbonation, six of which served to study creep, six were used to study the reversibility of creep deformations, and three unloaded samples were used to determine thermal deformations.

For all series, the pressure in concrete was assumed to be equal to 0.3 percent of the prism strength of non-carbonated samples — prisms at their 10% humidity.

Experimental data on the development of a creep value for gas-ash concrete compression with varying degrees of carbonation are shown in Figure 1, a, from which it follows that with the increase in the degree of carbonization of concrete, both the value of the creep deformation and the rate of its growth increase. With the duration of observations equal to 720 days, the creep value for non-carbonized concrete was 35 • 10^{-5} (MPa) $^{-1}$.

At the same time, the samples brought to a degree of carbonization of 38, 45, 59, and 66% have creep values of 70, 203, 380, and 412 • 10^{-5} (MPa) $^{-1}$, respectively.

Figure 1b presents the data on the degree of reversibility of the creep deformations of gas-ash concrete samples that have been present for 30 days under compression. According to this data, it is possible to conclude that the greater the degree of carbonization of concrete, the less reversibility of its creep deformations. For example, after 690 days after unloading, the C (t) 1 / C (t) ratio, which characterizes the degree of reversibility of concrete creep deformations (where C (t) 1 is the value of the reverse creep after unloading), for non-carbonated samples, it was 0.78. However, for the samples with degree of carbonization 38, 45, 59 and 66% were equal to 0.57; 0.42; 0.26 and 0.22, respectively.

III. Results

The obtained experimental data on the creep and reversibility of creep deformations of a gas-ash concrete with various degrees of carbonization can be explained from the physicochemical point.

When exposed to carbon dioxide, the chemical and mineralogical composition of autoclaved aerated concrete changes: a hydrosilicate crystalline intergrowth decomposes, calcium carbonate is formed and silica gel and free water are released. With the increase in the degree of carbonization in concrete, the content of the gel portion increases and the volume of the crystalline part of the solid phase decreases; the increase in the absolute specific surface of the concrete occurs. The microdamage of the concrete structure is growing due to the conversion of hydrated calcium silicate to calcium carbonate.

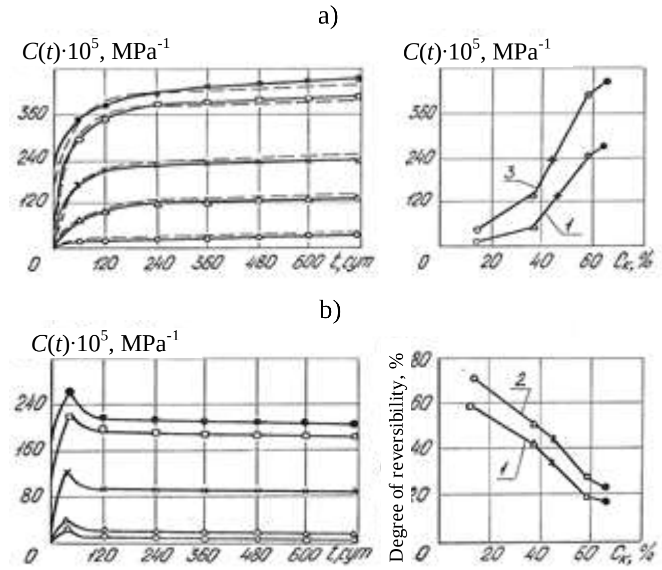

Fig. 1. Influence of carbonization on creep (a) and reversibility (b) of creep deformation of gas-ash concrete

Degree of carbonization: o – 13%; Δ – 38%; x – 45%; □ – 59%; ● – 66%
——— experimental curves;
– – – — curves, obtained on the basis of the equation (1);
1, 2, 3– duration of the observations respectively in 30, 90 and 720 days

According to the existing hypotheses about the creep mechanism of cement stone of Z.N. Tsilosani and A.E. Sheikin [8, 9] the above-mentioned changes occurring in autoclaved aerated concrete as a result of the increase in its degree of carbonization should increase its creep and reduce the reversibility of creep deformations, which is observed in our experiments.

Mathematical processing of the experimental data obtained by the authors (Fig. 1, a) allowed approximating the relation between the creep value C (t - τ) and the degree of carbonization of concrete C_k, % with the help of the following formula:

$$C(C_k, t-\tau) = A\left[1 - e^{-\gamma\frac{(t-\tau)\cdot C_K}{C_K+45}}\right], \qquad (1)$$

where $A = (251{,}36 + 63{,}42\sqrt{C_k - 45}) \cdot 10^{-5}$ (MPa)$^{-1}$;

$\gamma = 0{,}035$(day)$^{-1}$; $13 \le C_к \le 66$;

$(t - \tau)$ – duration of observation, day.

All the numerical values of the coefficients in the formula (1) were selected by the method of least squares.

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