Features Of The Formation Of The Structure And Properties Of Aerated Concrete Due To Its Forced Carbonate Hardening

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Abstract. The results of experimental studies on the establishment of the possibility of using carbon dioxide in the production of concrete for the purpose of improving its strength characteristics are presented. Specific features of physicochemical transformations occurring in the body of porous concrete during the organization of its hardening in environments with a high concentration of carbon dioxide are revealed. It was found that when lime is introduced into the cement binder composition, the degree of carbonation of portland cement hydration products decreases. It was shown that with successive steaming and forced carbonization of porous concrete on the basis of cement and cement-lime binder, conditions for both hydration and carbonate hardening are provided. This causes the appearance of a maximum amount of crystalline hydrate and carbonate neoplasms, which increases the strength of the material. The revealed features of the physicochemical processes of carbonization of cement and cement-lime systems allow us to speak about the effectiveness of the use of man-made CO₂ in the technology of production of unreinforced concrete products.

1. Introduction

At the present stage of the development of society, the issue of saving natural resources and reducing the level of pollution of the Earth's atmosphere with various man-made wastes and carbon dioxide is of great importance. Along with this, the construction industry is in need of high-quality efficient building materials and products. This predetermines the need to develop research in the field of obtaining economical and environmentally friendly materials and to introduce developed resource-saving technologies in production.

At present, concrete structures of various purposes are actively used in the construction industry. Most research in the field of concrete is aimed at optimizing existing technologies and processes of material structure formation, as well as expanding the raw material base of production. However, as a binder, portland cement is mainly used, the production of which is not environmentally friendly and is accompanied by the release of a large amount of carbon dioxide [1]. In connection with this, it is urgent to study the use of CO₂ in building materials technology based on cement and cement-lime binder in order to reduce its emissions into the atmosphere.

2. Analysis of publications, materials, and methods

The process of absorption and binding of carbon dioxide by building materials has been studied for a long time. In a number of cases, carbonization can have both a positive and a negative effect on the
physical and mechanical properties of building composites. Thus, for example, materials based on lime as a result of interaction with carbon dioxide increase the strength and longevity [2-5]. And when considering the issue of carbonization of concrete, the scientific interest in the process of binding free calcium hydroxide is most often reduced to the problem of carbon dioxide corrosion [6, 7]. This is due to the fact that free lime and hydrated products of portland cement clinker, providing structure formation and hardening of concrete, transfer to other compounds to form calcium carbonate under the influence of CO₂. Low resistance in the conditions of carbon dioxide aggression is possessed by low-basic calcium hydroxides of the tobermorite group. Also, the least resistant to carbonization are calcium hydroaluminates, which as a result of the reaction give aluminum hydroxide, calcium carbonate and water [8].

At the same time, it was found that the secondary calcium carbonate, which is formed by the interaction of carbon dioxide and free calcium hydroxide, contributes to an increase in weather resistance and, therefore, positively affects the life of cemented unreinforced concrete [9-12]. The carbonized layer in this case acts as a barrier on the surface of the material, which compacts the concrete surface and reduces its permeability. Previously, studies have been conducted that allow one to speak of a positive effect during the carbonation of concrete during the early hydration of concrete mix [13-15]. It was shown that the basic clinker minerals, two- and tricalcium silicate, react with carbon dioxide to form calcium silicate hydrate mixed with calcium carbonate. It was found that when carbonizing freshly hydrated cement, the reaction products obtained are nanosized and uniformly distributed, and the strength indexes increase to 26% [13].

Proceeding from the foregoing, it is expedient to study the effect of forced carbonization on the processes of structure formation and the physical and mechanical properties of the material on the basis of cement and cement-lime systems with a developed surface, for example, aerated concrete.

The purpose of this work is to study the features of physical and chemical transformations in the body of aerated concrete based on cement and cement-lime binder, hardening in specially created conditions with an increased concentration of carbon dioxide.

The studies were carried out on prototypes of aerated concrete of mark D600 measuring 100x100x100 mm. As components of the binder, portland cement of mark CEM I 42.5H produced by OAO Novorosscement (OJSC Novorosscement) and calcium lime produced by AO Evpatoria Building Materials Plant (JSC Evpatoria Building Materials Plant) of 80% activity were used. The binder content in the raw mixture was 50% by weight. The ratio of cement and lime in a mixed binder was 3:1. As a filler, quartz sand was used.

The chemical composition of the feedstock was determined by X-ray fluorescence analysis using an Epsilon 3XLE ED spectrometer (PANalitical). The results of the analysis are presented in Table 1 and Table 2.

Table 1. Chemical composition of cement.

|          | MgO  | Al₂O₃ | SiO₂ | SO₃  | K₂O  | CaO  | TiO₂ | MnO  | Fe₂O₃ | ZnO  | SrO  |
|----------|------|-------|------|------|------|------|------|------|-------|------|------|
| Portland | 0.610| 4.141 | 19.836 | 4.728 | 0.873 | 62.931 | 0.212 | 0.081 | 3.893 | 0.042 | 0.155 |
| cement   |      |       |       |      |      |       |      |       |       |      |      |

Table 2. Chemical composition of lime.

|       | MgO  | Al₂O₃ | SiO₂ | SO₃  | Cl   | CaO  | MnO  | Fe₂O₃ |
|-------|------|-------|------|------|------|------|------|-------|
| Lime  | 0.385| 0.346 | 0.286 | 1.019 | 0.051 | 97.889 | 0.030 | 0.253 |

Hardening was organized in two ways: steaming and steaming, followed by aging in a gas-air environment with a high concentration of carbon dioxide. Thermal treatment was carried out for 8 hours at a temperature of 60°C. Carbonization was carried out for 2 hours at a content of 40% CO₂ in a gas-air environment. The compressive strength of aerated concrete samples and their mineralogical composition were determined at the age of 1 and 28 days after drying. The mineralogical composition
of the samples was determined using a system of high-temperature synchronous TGA/DTA/DSC STA 8000 analysis by Perkin Elmer in a temperature range of 30-1000°C at a heating rate of 10°C/min, in a nitrogen medium.

3. The results and their analyses
Figures 1-4 show the results of studying the mineralogical composition of the surface layer of aerated concrete samples on a cement and cement-lime binder after 1 day of hardening, depending on the post-molding treatment regime.

![Figure 1. Derivatogram of a sample of aerated concrete on the basis of a cement binder after steaming at the age of 1 day.](image1)

![Figure 2. Derivatogram of a sample of aerated concrete on the basis of a cement binder after steaming and forced carbonization at the age of 1 day.](image2)

![Figure 3. Derivatogram of a sample of aerated concrete on the basis of a cement-lime binder after steaming at the age of 1 day.](image3)

![Figure 4. Derivatogram of a sample of aerated concrete on the basis of a cement-lime binder after steaming and forced carbonization at the age of 1 day.](image4)

The obtained DTA curves have three main endothermic effects. The temperature interval 130-180°C characterizes the process of dehydration of the hydrosilicate phase, ettringite, hydrosulfoaluminates and, possibly, calcium hydrosulfosilicates. The second endothermic effect in the temperature range 480-530°C indicates the presence of portlandite in the system. And the third effect in the interval 750-850°C characterizes the process of decomposition of calcium carbonate CaCO₃ [16-18]. In samples not subject to forced carbonization, the presence of calcium carbonate can be justified by the interaction of free lime with carbon dioxide during the drying of samples and measurement.

When analyzing the derivatograms of the samples on a cement and cement-lime binder, it was found that both portlandite and cement hydration products reacted with carbon dioxide during the carbonation process. This is evidenced by a decrease in mass in the temperature range 130-180°C and 480-530°C. However, it should be noted that when carbonizing samples on a cementitious binder, the loss of the samples mass at a temperature of 500-510°C decreased from 1.934% to 1.235%, which is 36% of the initial value (figure 1, 2). And in the cement-lime binder samples, the mass in the same
range decreased by 67% from 3.786% to 1.248% (figure 3, 4). This may be due to the fact that the endothermic effect in this temperature range characterizes the presence not only of free lime, which quickly reacts with carbon dioxide, but also of the CaOH+ groups present in the C-S-H phase.

Also, when introducing free lime into the lime-cement binder after carbonization, there is a decrease in the difference in mass loss in the temperature range 130-180°C compared to the samples on a cement binder. So, after carbonization, the mass of cement samples in this range decreased by 28% from 7.332% to 5.311% (figure 1, 2), and the samples with lime content – by 21% from 4.990% to 3.966% (figure 3, 4). This phenomenon may be due to the low resistance of Ca(OH)_2 to carbonization in comparison with the products of hydration of cement. As a result of the interaction of lime with carbon dioxide, calcium carbonate is formed, which, to some extent, can play the role of a colmatant and slow down the process of further carbonization of hydrates of clinker minerals [19].

Further, the mineralogical composition of the surface layer of aerated concrete samples was studied on the basis of cement and cement-lime binders at the age of 28 days after steaming and steaming with forced carbonization (figure 5-8).

When analyzing the derivatograms of samples on a cement and cement-lime binder at the age of 28 days, it was found that during the hardening of steamed and carbonized samples, the amount of free lime in the system is significantly reduced. This is evidenced by the absence or insignificant manifestation of the endothermic effect in aerated concrete samples in the temperature range 480-530°C. This is due to the fact that during the hydration hardening of the cement binder, free lime binds...
to various cement formations. There is also an effect in the range 700-750°C, which is characteristic for the decomposition of calcium hydrosilicates and, probably, the C-A-S-H phase, the dehydration of which is accompanied by a pronounced endothermic effect [20].

To confirm the possibility of using carbonization as a way to increase the physical and mechanical properties of concrete on both cement and cement-lime binder, tests were conducted to determine the strength of aerated concrete samples depending on the type of binder and the conditions for hardening. The data obtained are presented in Table 3.

Table 3. Compressive strength of aerated concrete samples, MPa.

| Type of binder       | Steaming | Steaming + carbonization |
|----------------------|----------|--------------------------|
|                      | 1 day    | 28 days                  |
| Portland cement      | 1.2      | 1.7                      |
| Portland cement + lime | 0.7      | 1.2                      |

When analyzing the results obtained, the compressive strength of aerated concrete is increased after forced treatment with carbon dioxide. Thus, for example, after steaming and carbonization, the strength of the samples on the cement binder in the first day increased by 25%, and at the age of 28 days – by 19%. The process of reducing the strength of aerated concrete samples by 28 days is due to the binding of a significant part of free lime when interacting with carbon dioxide and slowing down the hydration processes of cement minerals. Carbonized samples on the cement-lime binder in comparison with the samples after steaming at the age of 1 day increased their strength by 36%, and after 28 days of hardenings they have a strength 35% higher. Based on the data obtained, it can be concluded that forced carbonization is most effective when using a lime-cement binder.

4. Conclusion

Thus, as a result of the combined hardening of aerated concrete based on cement and cement-lime binder, including steaming and subsequent soaking in a medium with a high concentration of CO₂, conditions are ensured for both hydration and carbonate hardening. This ensures the appearance of a maximum number of crystalline neoplasms and an increase in the strength characteristics of the material. The revealed features of the physico-chemical processes of carbonization of cement and cement-lime systems allow us speak about the effectiveness of the use of man-made CO₂ in the production technology of unreinforced concrete products.

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