

FEATURES OF CARBONATING HARDENING OF LIGHTWEIGHT CONCRETE

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INTRODUCTION

The task of the concrete hardening acceleration becomes very important in developing of the saving technologies of the concrete products.

The maximum speed of the concrete hardening can be obtained by treatment compositions in carbon dioxide[1].

The continuous process of the carbonization gives an opportunity to make the material with specified properties. To achieve this effect it is necessary to optimize the recipe and the processing modes.

The purpose of the work is to develop a rational technological methods and parameters of the expanded clay lightweight concrete products processing in carbon dioxide that allows getting the material with specified physical and technical properties with minimal duration of hardening.

1. PROBLEM FORMULATION

The increased initial strength of the concrete is connected with acceleration of the hardening process of the cement in the very early period. Slowing the rate of hydration of binders can be explained by formation of a colloidal dispersion of the hydration shells around the grains. The reasons of formation of such shells are the small diffusion coefficients hydrate neoplasms and the supersaturation in the boundary layer that prevents the dissolution of the new cement portions and slows down its hydration and hardening. The supersaturation of the liquid phase of the cement paste is caused by the calcium hydroxide. Thus the acceleration the formation of a new phase and the reduction in the degree of supersaturation can be obtained by using the reaction of compound of calcium oxide with carbon dioxide. The carbon dioxide transforms a stand-lime to practically insoluble calcium carbonate. At the beginning the crystals of such calcium carbonate turn to crystallization basis and then give an additional bond to strengthen the cement stone.

In theory all calcium-containing components of the cement stone are capable of carbonation. The only exception is the compounds that include CaSO_4 . The reaction of CO_2 with Ca(OH)_2 proceeds with the evolution of the one mole of water. In a result the humid state of the material can be changed. In that case the favorable will be an exothermic effect that causes intense drying of the system. On the other hand, by carbonation hardening the water will be mostly the environment in which takes place the dissolution of the initial binder phase and their transportation to a reaction zone. The water becomes the main structural part of the emerging neoplasms only when the water carbonates formed. The neoplasms mostly were formed in a reaction zone that located at a distance from the surface of the dissolving starting material. The neoplasms can also be formed in a close proximity to the surface of the dissolving starting material if the humidity of the carbonized samples will be decreased noticeably. As a result that will block further reaction passing and the process will slow down strongly.

Along with hydrates carbonization can take place the "Carbonate" dissolution of the starting materials [1]. This is due to the fact that the irreversible transfer of Ca(OH)_2 to CaCO_3 disturbs the dynamic balance between the initial phase and the solute in Ca^{2+} ions that leads to the intensive dissolution. The selective dissolution and carbonization of the separate component parts of cement occur in the downstream row that matches to the downlink solubility and hydrated oxides of compounds. At first the calcium hydroxide enters into the reaction and after that the hydrated calcium oxide compounds enters too. In addition to reactions described above the calcium Hydrosilicates polymerization can also take place when CO_2 effect on cement paste. That leads to the insoluble polysilicate formation [2].

During carbonation hardening the changes in a moisture state of the material can slow down the carbonization process. In connection to this it is necessary to work out the technological methods that will reduce the water content of concrete compound on the stage of its preparation and that

will provide the excess water extraction from the cement matrix during the hardening. Moreover for the efficient continuous flow of carbonation reaction it is necessary to make an optimally developed structure of the compacted concrete compound. Such structure will provide the bulk diffusion of carbon dioxide into the product and connected to this volumetric change of neoplasms on the one hand and the mudding of the pore structure with neoplasms as a result of the local bulk increase of the solid phase during the carbonization process on the other hand.

All this actions and the optimization of the binder composition and the processing modes have to provide efficiency of the carbonization process of the product that allows obtaining the material with specified mechanical and physical properties while dramatically reducing the production cycle.

2. RESEARCH METHODOLOGY

The experimental device was built to carry out artificial carbonization of control samples and concrete samples. This experimental device consists of autoclave, vacuum pump, Carbon dioxide cylinders with reducers, control devices and pressure hoses. The device made it possible to carbonize up to 18 cube samples with an edge of 100 mm according to a given regime at the same time. Freshly molded concrete samples were previously subjected to evacuation to a vacuum of 0.085 ... 0.095 MPa. As a result, a porous capillary system was created in the samples under vacuum. After that carbon dioxide gas was supplied stepwise to the required excess pressure. The device allows to carry out the carbonization modes at excess pressure up to 1.5 MPa for a predetermined time interval.

In the studies, a complex of physicochemical and optical methods was used, including differential-thermal and X-ray diffraction analyzes, as well as electron microscopy in the studies.

During the optimization of prescription and technological conditions for the production of carbonized expanded clay concrete, mathematical methods of experiment planning were used. An experimental plans of the second order, close to the D-optimal one were used.

3. RESULTS AND DISCUSSION

The optimization of the recipe and technological parameters of the carbonized

expanded clay lightweight concrete included: working out an economical concrete compositions, working out the optimal carbonization modes, researching the possibility to intensify the carbonization process by inserting a binder into the composition (milled limestone) and by decreasing the total water content of the concrete mixture.

The carbonization process can be activated by intensive introduction of gas reagent into the reaction zone. That can be achieved by using carbonization regimes with preliminary vacuuming and subsequent filing of carbon dioxide under pressure. The vacuuming of freshly made concrete provides the creation of rarefaction in capillary-porous system. After that the carbon dioxide pressure drop in the initial period provides the vacuum removal, effective self-consumption of the reagent and the intensification of the carbonization process.

The process of "carbonate" dissolution of initial cement minerals accelerates proportionally to concentration of the carbon dioxide in reaction zone. That's why the use of regimes with CO₂ overpressure allows to rule the structuring process of cement compositions. At the same time carbonization of the product under the pressure leads to creation of the high saturations in the system and to local increase of the solid phase bulk. That entails the emergence of a significant internal tension and the development of destructive processes in the concrete structure. In this circumstances the use of stepwise pressure rise of CO₂ to the desired value allows to eliminate destructive processes that take place while the single-stage carbonization. It was established experimentally that the use of stepwise pressure rise of CO₂ allows to increase the demoulding strength of the expanded clay lightweight concrete in 10...30 percent [3].

It was found the an efficient replacement of 20...30 percent of the cement on the milled limestone without changing the physical and mechanical properties of the material [4]. While the carbonization hardening the basic component of the crystal structure is the calcite. The results of the X-ray examination and the differential thermal studies of the cement stone confirmed that. A massive morphological changes arise under the CO₂ effect in the cement matrix. The increase of the pressure, processing time and temperature leads to the matrix compaction and to the reduction of micropores and microcapillaries as compared with untreated samples. The flat, plate-like structures (inherent in portland lime stone) and thin needle-like crystals of ettringite are absent. Instead of them there are

rounded, densely arranged round crystals without any pores and the crystals in the structure of treated samples.

In connection to aforesaid it is obviously that crystallization of neoplasm occurs at the surface of carbonates grains. As a result such carbonates grains accrete with a fused between well-developed crystals of a new phase. The electron microscopic analysis confirmed the lasting nature of accretion between a carbonate rock and a secondary calcite generation. That leads to the structure hardening. The carbonate rock serves as a substrate. That occurs thanks to the proximity of crystallographic cells.

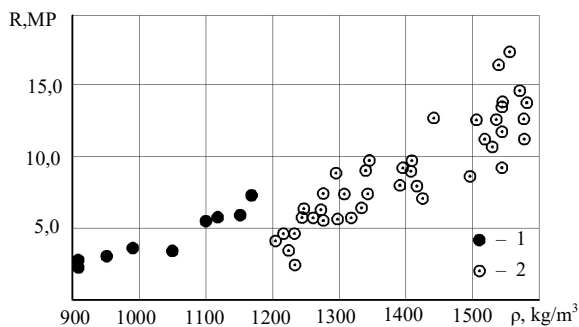


Figure 1. The relationship between the demoulding strength and the density of the carbonized keramsit:

- 1 – concrete based on expanded clay aggregate gravel ($\rho_{bulk} = 450 \text{ kg/m}^3$);
2 – concrete based on expanded clay aggregate gravel ($\rho_{bulk} = 720 \text{ kg/m}^3$).

In conditions of carbonization hardening the super plasticizer addition introduction into the concrete mix provides technological concrete mixtures with low water content. After the cement mixture compaction the dehydration of cement mixture occurs as a result of self evacuation. In this case the capillaries are exempted from moisture and become gas-proof. The volume of solid increase during the process of binding up CO_2 by hydrolysis products of cement minerals. That process is accompanied by pore structure mudding and leads to the increase of concrete strength.

The increased CO_2 concentration effects on initial concrete strength noticeably in the reaction zone [5]. The increase of the amount of CO_2 pressure from 0,6 to 1,2 MPa leads to increase of the CO_2 concentration and as a result to increase of the concrete strength in one hour after the carbonization of 25...60 percent. The increase of the duration of treatment from 30 to 60 minutes leads to increasing concrete strength of 5...20 percent. The influence of carbonization regimes on

the concrete strength is equalized with increasing concrete age. As a result the strength of the same dense concrete can vary widely after the carbonization (Fig.1).

The four tested lightweight aggregate compositions were selected for researching the growth of the kinetic strength during the time. All compositions have different consumption and composition of the binder.

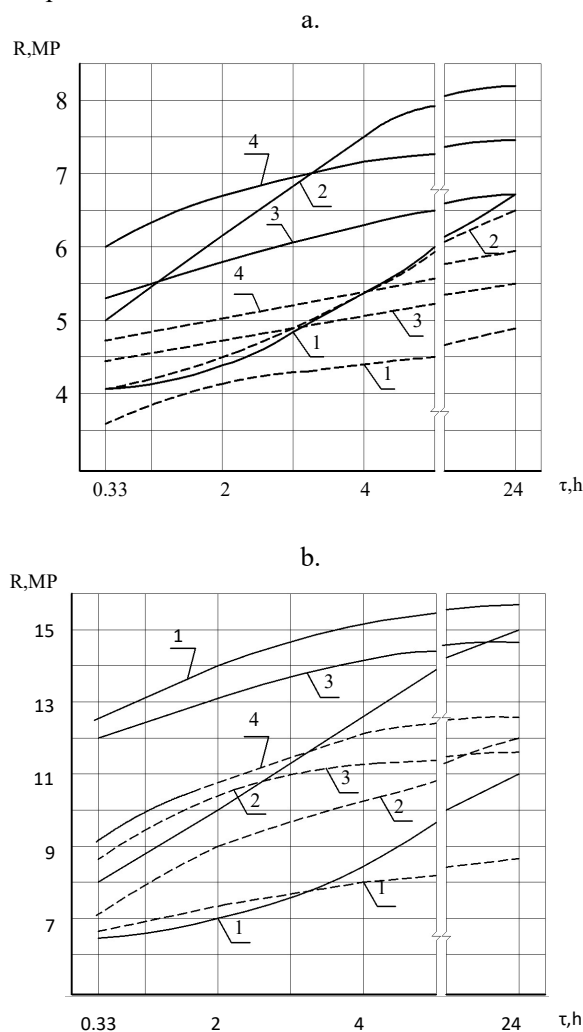


Figure 2. The growth of expanded clay lightweight concrete strength in early age after the carbonization (a – compositions 1 and 2; b – compositions 3 and 4):

- 1 – carbonization by regime: $R_c = 0,6 \text{ MPa}$, $\tau_c = 20 \text{ min}$;
2 – carbonization by regime: $R_c = 0,6 \text{ MPa}$, $\tau_c = 40 \text{ min}$;
3 – carbonization by regime: $R_c = 1,2 \text{ MPa}$, $\tau_c = 20 \text{ min}$;
4 – carbonization by regime: $R_c = 1,2 \text{ MPa}$, $\tau_c = 40 \text{ min}$;

The analysis of strength changes of expanded clay lightweight concrete in early age (20 min, 2 hours, 4 hours, 24 hours after carbonization) showed the maximal demoulding strength after applying the carbonization regimes with the maximal CO₂ concentration and pressure value in the reaction zone. After applying the carbonization regimes with pressure value 1,2 MPa and carbonization time 20...40 min the demoulding strength were 70...75 percent from the one after 28 days (Fig. 2 a, b).

The decreasing of the CO₂ concentration by applying carbonization regimes with pressure value 0.6 MPa provides reaching 50...60 percent of the concrete strength from the ones after 28 days for concrete classes B5-B7,5 (compositions 1 and 2) and 34...45 percent of the concrete strength for concrete classes B10-B15 (compositions 3 and 4).

The use of porous sands in structurally-insulated concretes leads to producing the products with a residual moisture above permissible. During the carbonization process the free water is released with exothermic effect as a result of the chemical interaction of carbon dioxide and hydration and hydrolysis products of binder minerals. In consequence of this after the demoulding the residual moisture of the expanded clay lightweight concrete was 9,4-13,5 percent for concretes with 920...1000 kg/m³ density and 10,6...13,1 percent for concretes with 1200...1550 kg/m³ density. The injection of the superplasticizer allows to reduce the residual moisture by 0,5...3,5 percent depending on concrete composition.

4. CONCLUSIONS

1. It had been studied the mechanism of structuring of the cement compositions in conditions of artificial carbonization. And the main rational methods of intensification of hardening process were found.

2. It had been offered the rational technological parameters and formulas of carbonization technology of the lightweight aggregate concrete wall products:

- the effective replacement of 30 percent of cement by milled limestone without changing the level of indexes of physical and mechanical properties of the material;
- the optimal granulometry of porous fillers;
- the optimal carbonization regimes that use the preliminary mixture vacuuming and the step processing mode in carbon dioxide.

3. The maximal demoulding strength had been provided under carbonization regimes with a maximal CO₂ concentration in reaction zone that is characterized by maximal pressure value.

References

1. **Sorochkin M.A., Shurov A.f., Uriev N.B.** *The carbon dioxide influence as the method of intensification of cement hydration/ DAN the USSR.1970. №1 - p.149-151.*
2. **Ramachadran V., Feldman R., Boduen J.** *The science of concrete.- Stroyizdat, 1986.- p. 261-262.*
3. **C.A. 1320202 the USSR, MKI C 04 B 40/2.** *The method of manufacturing concrete products/ Michailenko G.V., Solomatov V.I., Gara A.A.- Pub. In B.I., 1987, №24 - 6p.*
4. **Michailenko G.V., Gara A.A.** *The physical and mechanical properties of keramsit that had been hardened under carbonization.// The new effective materials in building.- Ashhabad, 1986.-p.93-94.*
5. **Lubomirsky N.V., Srebnik V.M., Bahtin A.S.** *The building composites on the lime basis of the carbonated hardening type/ Motrol. Motoryzacja i energetyka rolnictwa. – Simferopol-Lublin. - 2009. - Vol. 11A. - p. 229 – 238.*