

RECIPE-TECHNOLOGICAL FEATURES OF CARBONIZATION HARDENING OF LIGHTWEIGHT CONCRETE

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Abstract: The work is devoted to researching the parameters of expanded clay lightweight concrete technology by using carbonation hardening that allows to maximally intensify the process of carbonization using methods such as decreasing the total water content in the system, applying optimal structure and formula concrete compositions, processing the products in carbon dioxide environment. The mechanism of structure formation of concrete compositions in conditions of artificial carbonation was studied. It was formulated using the basic techniques of rational intensification of the hardening process. Rational formulation and technological parameters of carbonization technology of lightweight aggregate concrete wall products were proposed: effective replacement of almost 30 per cent of concrete by powdered lime rock in process of carbonization without changing the physical and technical properties of material; the optimal size of porous aggregates; the optimal modes of composite carbonization that include preliminary placement in vacuum and step processing in carbon dioxide environment. The maximum demoulding strength of expanded clay lightweight concrete was received by using maximum concentration of carbon dioxide during carbonization in reaction area that is characterized by the maximum pressure value. In addition, the properties of concrete in an early stage after the carbonization were explored.

Keywords: carbonating hardening; cement stone; compounding-technological parameters; expanded clay lightweight concrete; kinetics of growth of durability.

1 INTRODUCTION

The task of the concrete hardening acceleration becomes very important in developing the saving technologies that save the concrete products. The maximum speed of the concrete hardening can be obtained by treatment compositions in carbon dioxide. The continuous process of 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.

2 THE PURPOSE AND OBJECTIVES

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

3 MECHANISM OF STRUCTURING OF THE CEMENT COMPOSITIONS

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 for the formation of such shells are small diffusion coefficients of hydrate neoplasms and 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 calcium hydroxide. Thus the acceleration of 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. 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 one mole of water. As a result, the humid state of the material can be changed. In that case, an exothermic effect that causes intense drying of the system will be favourable. On the other hand, by carbonation hardening water will mostly be the environment in which the dissolution of the initial binder phase and the transportation to a reaction zone take place. The water becomes the main structural part of the emerging neoplasms only when the water carbonates form. Neoplasms were mostly formed in a reaction zone that located at a distance from the surface of the dissolving starting material. Neoplasms can also be formed in a close proximity to the surface of the dissolving starting material if the humidity of the carbonized samples is decreased noticeably. As a result, that will further block the passing reaction and the process will slow down significantly.

Along with hydrates carbonization "carbonate" dissolution of initial minerals can take place [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 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 is followed by hydrated calcium oxide compounds. In addition to reactions

described above the calcium hydrosilicates polymerization can also take place when CO_2 affects cement paste. That leads to the insoluble polysilicate formation [1].

During carbonation hardening the changes in a moisture state of the material can slow down the carbonization process. Therefore, 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 enable bulk diffusion of carbon dioxide into the product and, in relation to this, volumetric change of neoplasms on one side 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.

All these 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.

4 THE OPTIMISATIONAL COMPOSITION METHODS

The optimization of the recipe and technological parameters of the carbonized expanded clay lightweight concrete includes the following: working out 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 carbon dioxide in reaction zone. That is why the use of regimes with CO_2 overpressure allows ruling the structuring process of cement compositions. At the same time carbonization of the product under the pressure leads to creation of 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 these circumstances the use of stepwise pressure rise of CO_2 to the desired value allows to eliminate destructive processes that take place during the single-stage carbonization. It was established experimentally that the use of stepwise pressure

rise of CO_2 allows increasing the demoulding strength of the expanded clay lightweight concrete in 10-30 % [2].

The efficient replacement of 20-30 % of the cement on the milled limestone without changing the physical and mechanical properties of the material was found [3]. During the carbonization hardening the basic component of the crystal structure is calcite; the results of the X-ray examination and the differential thermal studies of the cement stone confirmed it. Massive morphological changes arise under the CO_2 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 relation to the aforesaid, it is obvious that crystallization of neoplasm occurs at the surface of carbonate grains. As a result, such carbonate grains accrete with the 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.

In conditions of carbonization hardening adding of the super plasticizer 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 increases during the process of binding up CO_2 with 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 noticeably affects the initial concrete strength in the reaction zone [4]. 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 %. The increase of the duration of treatment from 30 to 60 minutes leads to increasing concrete strength of 5-20 %. 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).

5 EXPERIMENTS AND RESULT DISCUSSION

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

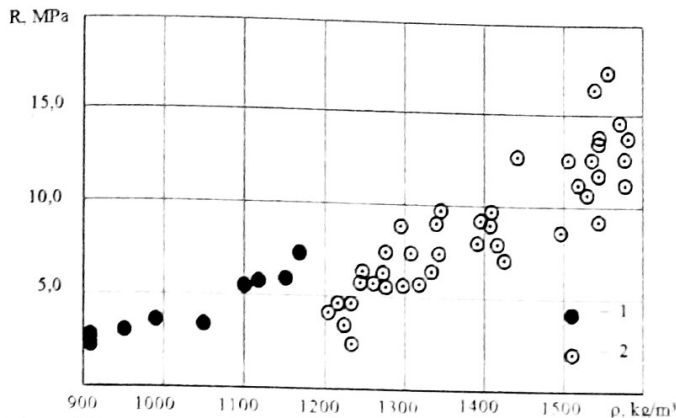


Figure 1 The relationship between the demoulding strength and the density of the carbonized keramsit.

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

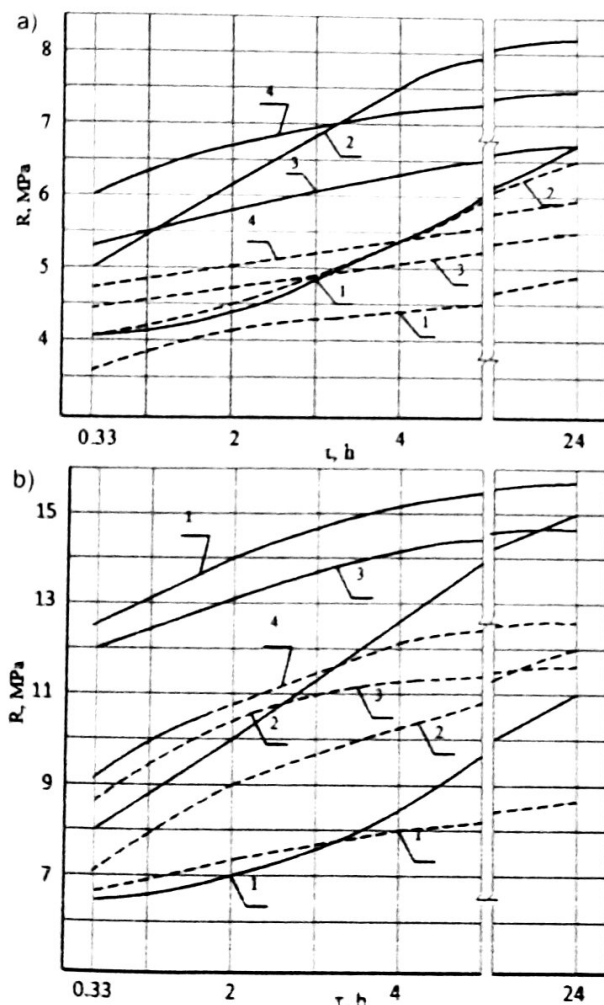


Figure 2 The growth of expanded clay lightweight concrete strength in early age after the carbonization (a – compositions 1 and 2; b – compositions 3 and 4). 1 – carbonization by regime: $R_c = 0.6 \text{ MPa}$, $\tau_c = 20 \text{ min}$; 2 – carbonization by regime: $R_c = 0.6 \text{ MPa}$, $\tau_c = 40 \text{ min}$; 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 CO_2 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 was 70-75 % of the one after 28 days (Fig. 2 a, b).

The decrease of the CO_2 concentration by applying carbonization regimes with pressure value 0.6 MPa provides reaching 50-60 % of the concrete strength of the ones after 28 days for concrete classes B5-B7.5 (compositions 1 and 2) and 34-45 % 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 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, after the demoulding the residual moisture of the expanded clay, lightweight concrete was 9.4-13.5 % for concretes with $920\text{-}1000 \text{ kg/m}^3$ density and 10.6-13.1 % for concretes with $1200\text{-}1550 \text{ kg/m}^3$ density. The injection of the superplasticizer allows to reduce the residual moisture by 0.5-3.5 % depending on concrete composition.

6 CONCLUSION

The mechanism of structuring of the cement compositions in conditions of artificial carbonization has been studied. The main rational methods of intensification of hardening process were found.

The rational technological parameters and formulas of carbonization technology of the lightweight aggregate concrete wall products have been offered:

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

The maximal demoulding strength has been provided under carbonization regimes with a maximal CO_2 concentration in reaction zone that is characterized by maximal pressure value.

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7 REFERENCES

- [1] Ramachadran, V.; Feldman, R.; Boduen, J.: The science of concrete, Stroyizdat, Moskva, 1986.
- [2] Michailenko, G. V.; Solomatov, V. I.; Gara, A. A.: The method of manufacturing concrete products, C.A. 1320202 the USSR, MKI C 04 B 40/2., Pub. In B.I., 1987, №24- 6p.
- [3] Michailenko, G. V.; Gara, A. A.: The physical and mechanical properties of keramsit that had been hardened under carbonization, Proc. The new effective materials in building, Ashhabad, 1986, 93-94
- [4] Lubomirsky, N. V.; Srebnyk, V. M.; Bahtin, A. S.: The building composites on the lime basis of the carbonated hardening type Motrol, Proc. Motoryzacja i energetyka rolnictwa, Simferopol-Lublin, 2009, Vol. 11A., 229 – 238

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