Peculiarities of structure formation processes in non-autoclaved aerated concrete produced using industrial wastes

Andry Melnyk

Department of Building Production, Lviv Polytechnic National University, UKRAINE, Lviv, S. Bandery street 12, E-mail: melnyk.a@ukr.net

Following the strategy of sustainable development and the principle of applying the best available technologies, energy saving in Ukrainian Housing and Public Utilities Sector is achieved by constructing energy efficient buildings due to applying efficient building materials. Development of modern building technologies in all technologically advanced countries is aimed at developing cost-effective, efficient materials the use of which can reduce energy costs and consumption of raw materials. Aerated concrete is the optimal material for housing because it has wide density and durability range, the properties being important for solving various structural problems.

The aerated concrete based on the modified cementitious system containing an additional cementitious material, that of carbonate-bearing salt waste is characterized by the compressive strength of 2.7 MPa with the density of 650 kg/m^3 after 28 days of hardening.

Key words – aerated concrete, salt processing wastes, swelling multiplicity, strength, porous structure.

I. Abstract

The increased production of aerated concretes is caused by the increasing demand of housing construction. Recently, in construction industry a number of new regulatory documents have been adopted, aimed at reducing energy and raw materials consumption and improving quality and reliability of construction. Extensive use of non-autoclaved aerated concrete is one of the ways to increase thermal properties of external building envelopes in Ukraine. Research and practice in the field of non-autoclaved aerated concretes are aimed at improving product quality while reducing the cost of products.

Improving physical and mechanical properties of aerated concretes due to applying modified cementitious systems containing additional cementitious materials that change properties of partitions between pores is a relevant problem of nowadays.

II. Introduction

Aerated concrete is produced on the basis of Portland cement with the consumption of 400-500 kg/m^3. While producing aerated concretes it is possible to decrease cement consumption due to using lime-ash or ash-alkali cement binders as well as clinker binding compositions that are obtained from byproducts of metallurgical and chemical industries [1].

There are theoretical and experimental studies dealing with the use of fly ash from thermal power plants in technology of aerated concretes production. However, increase of fly ash in the content of aerated concrete reduces its mechanical strength [2].

It is known [3] that aerated concrete is characterized by formation of large amounts of unstable calcium hydroaluminates in its structure that negatively affect the strength of final products. In production of non-autoclaved aerated concrete there are added cementitious materials of fine dispersion that allow to directionally form the structure of inter-pore partitions with creation of stable hydration products.

Using industrial waste is of practical importance for building materials technology in general and aerated concretes technology, in particular, because it allows improving the basic material properties and increasing technical and economic performance; it will also improve ecology of the environment due to recycling industrial wastes [4].

It is relevant to create the cementitious systems that allow obtaining aerated concretes of improved performance quality with minimum production costs.

III. Results and Discussin

In experimental studies Portland cement PC - I 500 JSC "Ivano-Frankivskcement", fly ash from Burshtynska thermal power plant was used as a finely dispersed filler, as supplementary cementitious materials there were used salt processing wastes, such as carbonate-containing and sulfate components with. To approximate conditions of aerated concrete production, testing of cement paste was carried out at W/C = 0.41 which provides self-consolidating concrete 190 mm. The effect of adding cementitious materials on the strength of cementitious systems is presented in Table 1.

TABLE 1

THE EFFECT OF CARBONATE-CONTAINING WASTES (CW) AND SULFATE-CONTAINING WASTES (SW) ON THE STRENGTH OF CEMENTITIOUS SYSTEMS

Type and content of additives	Compressive strength limit, MPa, after days of hardening				
	1	2	7	28	90
PC - I 500	13.9	23.0	27.3	45.1	69.0
5 wt.% CW	14.6	27.5	45.1	37.9	65.9
10 wt.% CW	15.3	29.7	35.6	38.1	70.8
15 wt.% CW	7.3	14.9	23.6	30.9	36.1
5 wt.% SW	11.4	20.0	25.3	28.8	38.6
10 wt.% SW	10.0	16.6	17.8	24.4	36.0

After adding 5 wt.% of carbonate-containing waste to the cementitious system, its strength increases from 13.9 MPa to 14.6 MPa after one day of hardening in normal conditions (technical effect $\Delta R = 5.1\%$). After adding 10 wt. % of carbonate-containing waste to the cementitious system, its strength increases to 15.3 MPa ($\Delta R = 10.1\%$). The further increase of the amount of carbonate-containing waste to 15 wt. % reduces the cement stone strength to 7.3 MPa. During longer time of hardening the highest level of strength is shown by the cement stone including 10 wt. % of carbonate-containing salt wastes. Thus, the strength of the cement stone on the basis of the cementitious system after 90 days of hardening is 70.8 MPa, while the strength of the cementitious stone based on Portland cement PC I-500 is 69.0 MPa. Research into the effect of sulfate wastes on cementitious systems properties has established that introducing sulfate-containing components to the composition of cementitious systems causes a decline in the strength of cement stone during all periods of hardening.

It should be noted that introducing the sulfate salt waste into the composition of the cementitious system causes increase of Portland cement hydration in the early stages of hardening. Thus, after 2 days of hardening the degree of hydration of the modified cementitious system containing carbonate-bearing salt wastes is 49.9 %, whereas the degree of hydration of Portland cement is 23.7%.

The experimental studies showed the effects of carbonate-containing salt wastes and sulfate salt wastes on strength characteristics of aerated concretes. Adding salt wastes allows to improve the strength of aerated concrete during all periods of concrete hardening. Thus, when carbonate-containing salt waste is included, after 7 days of hardening the strength of non-autoclaved aerated concrete is 1.7 MPa (technical effect ΔR = 466%), maintaining average density of 650 kg/m^3 , while the strength of aerated concrete based on Portland cement is 0.3 MPa. After adding the sulfate component we can observe increase of the aerated concrete strength to 1.6 MPa (ΔR = 433%). After 28 days of hardening, the aerated concrete based on the modified cementitious system that includes carbonate-containing salt wastes has the strength of 2.2 MPa (technical effect ΔR = 175%) whereas the compressive strength of the aerated concrete based on ordinary Portland cement is 0.8 MPa. It should be noted that after adding a sulfate component the aerated concrete slurry cures quickly, thus increasing the density of aerated concrete, and therefore its strength. Aerated concrete with sulfate additives after 28 days of hardening has the compressive strength of 1.8 Mpa, but its density is 715 kg/m^3.

The results obtained by scanning electron microscopy are confirmed by X-ray diffraction analysis. Thus, after adding carbonate-containing salt wastes into the composition of aerated concrete, the X-ray diffraction pattern depicts intense lines corresponding to hydrocalumite $Ca_4Al_2(OH)_{14}\cdot 6H_2O$ (d/n=0.820; 0.388; 0.288; 0.245 nm.) that belongs to the group of aqueous hydroxides and may contain in its lattice a significant amount of anion CO_3^{2-}.

To study the processes of structure formation partitions between pores in aerated concrete based on modified cementitious systems, the modeling systems such as "$Ca(OH)_2$ - aluminum paste," "$Ca(OH)_2$ – carbonate waste product - aluminum paste", which hardened in normal conditions and after heat treatment were investigated. Today the big amount of aerated concrete is produced by using autoclaves and that increase energy costs and the cost of the material. According to X-ray diffraction analysis, stone based on the model system of "$Ca(OH)_2$ - aluminum paste" which was kept under normal conditions, lines of portlandite (d/n = 0,493; 0,263; 0,193 nm) and metastable hexagonal hydroaluminates calcium $2CaO \cdot Al_2O_3 \cdot 8H_2O$ (d/n = 1,07; 0,536; 0,287 nm) are fixed in all times of hardening.

The investigations of structure formation processes in a model system of "$Ca(OH)_2$ - aluminum paste" after heat treatment showed that there is a conversion of metastable hexagonal calcium hydroaluminate $2CaO \cdot Al_2O_3 \cdot 8H_2O$ in to stable hydrated phase - cubic calcium hydroaluminate $3CaO \cdot Al_2O_3 \cdot 6H_2O$ (d/n = 0,2286; 0,255; 0,442; 0,510 nm), which is accompanied by a change in volume hardens system.

According to X-ray diffraction analysis using carbonate waste product from processing of salt production as an supplementary cementitious material in the modeling system of $Ca(OH)_2$ - waste product - aluminum paste " hexagonal calcium hidroaluminates in the presence of $CaCO_3$ are replaced by a more stable hydrocarboaluminates $3CaO \cdot Al_2O_3 \cdot CaCO_3 \cdot 12H_2O$ (d/n = 0,760; 0,380 nm) structure role of which increases with time. Futhermore, there are lines of calcium carbonate (d/n = 0,303; 0,227; 0,208 nm) and portlandite (d/n = 0,493; 0,263; 0,193 nm) on diffractograms.

Conclusion

Application of salt processing wastes, on one hand, has a positive ecological effect as wastes are recycled; and, on the other hand, it has economic and technical effects. The aerated concrete based on the modified cementitious system containing an additional cementitious material, that of carbonate-bearing salt waste, and reinforced with polypropylene fibers is characterized by the compressive strength of 2.7 MPa with the density of 650 kg/m^3 after 28 days of hardening. The thickness of partitions between pores is 0.16 – 0.21 mm, and the number of small pores with the size 0.2-1.0 mm constitutes 76.4%.

References

[1] Popova E.A. Production of high-quality non-autoclaved aerated concrete with the account of the nature of additives: Synopsis of thesis for Ph.D./E.A.Popova. - Saint-Petersburg, 2006. – 24 p.

[2] Shchukina D.V. Non-autoclaved ash-cement aerated concrete with chloride and sodium sulfate: Synopsis of thesis for Ph.D./ D.V. Shchukina.- Saint-Peterberg, 2007. – 27 p.

[3] Mitina N.A. Production of durable non-autoclaved aerated concrete by adjusting the composition and properties of concrete mixtures: Synopsis of thesis for Ph.D./ N.A. Mitina. – Tomsk, 2003. – 20 p.

[4] Sanytsky M.A. Modified composite cements: A tutorial / M.A. Sanytsky, H.S. Sobol, T.E. Markiv. – Lviv: Lviv Polytechnic Publishing House, 2010 – 132 p.