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NON-AUTOCLAVED AERATED CONCRETE PRODUCED USING INDUSTRIAL WASTES

There is investigated the effect of carbonate-containing and sulfate salt processing wastes on the properties of cementitious systems and aerated concretes based on them.

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

Досліджено вплив карбонатвмісного та сульфатного відпадків переробки солі на властивості цементуючих систем та ніздрюватих бетонів на їх основі.

Ключові слова: газобетон, відпадки переробки солі, кратність спучування, міцність, порова структура.

Introduction

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 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.

Aerated concrete is produced on the basis of Portland cement with the consumption of 400-500 kg/m3. 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.

Materials and methods of investigation

In experimental studies Portland cement CEM I – 42,5R JSC "Ivano-Frankivskcement" with the following characteristics: specific surface S_{spec} = 350 m^2/kg; residue on the sieve № 008 – 1.1%; beginning of hardening – 3 h 20 min.; end of hardening – 6 h 10 min. is used.

Fly ash from Burshtynska thermal power plant was used as a finely dispersed filler with the following properties: true density – 2.21 g/cm^3 ; bulk density – 870 kg/m^3; residue on sieve № 008 – 8.7 wt.%; chemical composition, wt.% : SiO_2 – 54; Al_2O_3 – 23.75; Fe_2O_3 + FeO – 13.8; MgO – 1.91; CaO – 4.98; SO_3 – 0.53; K_2O + Na_2O – 0.25.

As supplementary cementitious materials there were used salt processing wastes, such as carbonate-containing and sulfate components with the following chemical composition, wt.%: carbonate-containing component: SiO_2 – 1.8, Al_2O_3 -1.64, Fe_2O_3 – 0.54, CaO – 39.42 , MgO – 4.21, Na_2 O – 6.42, R_2 O – 6.57; sulfate component: SiO_2 – 0.85, Al_2 O_3 – 1.01, Fe_2O_3 – 0.14, CaO – 31.47, MgO – 1. 38, Na_2O – 2.85, R_2O – 35.9.

Physical and mechanical properties of cementitious systems and aerated concretes based on them were determined by standard test methods.

Results and Discussion

An important technological feature in manufacturing aerated concretes aimed at providing the necessary average density and strength is creation of optimal conditions for two processes that occur simultaneously: gas release and curing of aerated concrete slurry. It is important to correlate the speed of gas release with that of aerated concrete curing. Before setting of the cement – water system occurs, the process of gas release must be as close to its end as possible.

The experimental studies of the effect of adding more cementitious materials on the time of cementitious systems hardening showed that including salt processing carbonate-containing waste (CW) in the amount of 10 wt.% into the cementitious system composition accelerates the time of hardening (Fig.1).

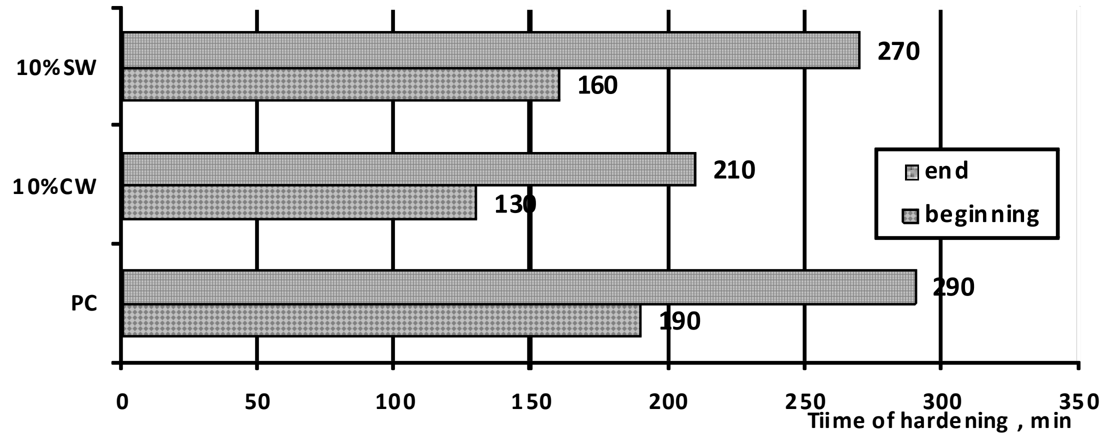


Fig. 1. The effect of adding supplementary cementitious materials on the time of cementitious systems hardening

The beginning setting time of such a system is 130 min. while that for Portland cement is 190 min.; hardening of the cementitious system containing carbonate wastes ends in 210 min., whereas for ordinary Portland cement hardening ends in 290 min. Introducing sulfate salt wastes (SW) to the cementitious system reduces the time of its beginning of hardening by 30 min., the time of the end of hardening is reduced by 20 min., compared with those for Portland cement.

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.

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 ΔR = 5.1%). After adding 10 wt. % of carbonate-containing waste to the cementitious system, its strength increases to 15.3 MPa (ΔR = 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.

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	W/C	Compressive strength limit, MPa, after days of hardening				
		1	2	7	28	90
PC – I 500	0.41	13.9	23.0	27.3	45.1	69.0
5 wt.% CW	0.41	14.6	27.5	45.1	37.9	65.9
10 wt.% CW	0.46	15.3	29.7	35.6	38.1	70.8
15 wt.% CW	0.48	7.3	14.9	23.6	30.9	36.1
5 wt.% SW	0.41	11.4	20.0	25.3	28.8	38.6
10 wt.% SW	0.44	10.0	16.6	17.8	24.4	36.0

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. Thus, after adding 5 wt.% of sulfate-containing components to the cementitious system, its strength declines by 18.3 % still after 1 day of hardening, after 7 days by 7.3 %, and after 28 days by 36.1 %. Further increasing the amount of sulfate components in the cementitious system to 10 wt.% , declines its strength by 27.9 % in 1 day, by 34.8 % in 7 days, and by 459 % in 28 days.

To obtain products with desired strength and average density, the technology of non-autoclaved aerated concrete production must have an important characteristic – swelling multiplicity, which later defines the characteristics of the aerated concrete. Studies of the kinetics of swelling of aerated concrete mixes that include salt processing wastes showed (Fig.2) that aerated concrete mix based on common Portland cement has the swelling time of 21 min.

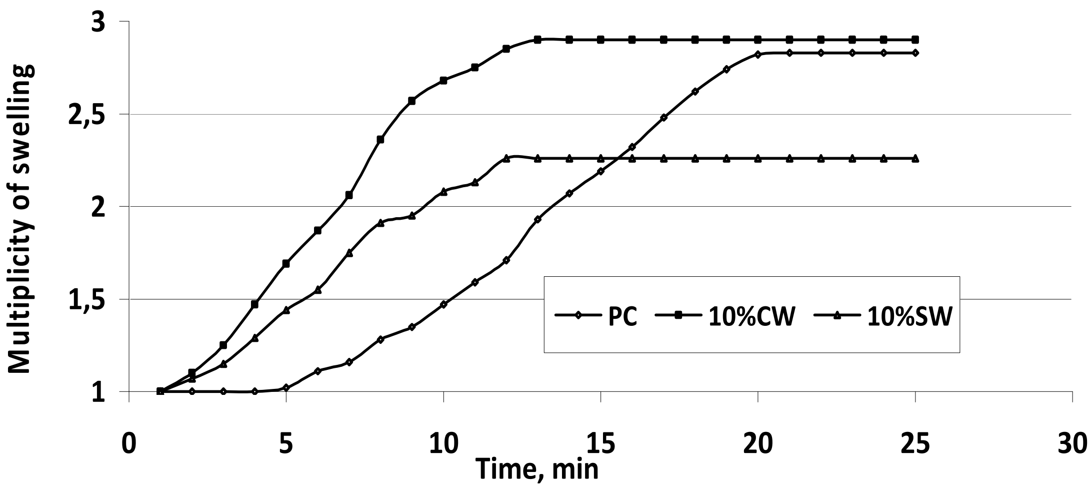


Fig. 2. Swelling kinetics of aerated concrete mass

After adding 10 wt.% of carbonate-containing salt waste we can observe reduction of the concrete array swelling time to 12-14 minutes, after adding sulfate component the time reduces to 9-11 min. It should be noted that multiplicity of swelling of the aerated concrete mix on the basis of the modified cementitious system including carbonate-containing salt wastes is 2.9, that including sulfate wastes is 2.3, while the multiplicity of swelling of aerated concrete mix based on Portland cement is 2.8.

The experimental studies showed the effects of carbonate-containing salt wastes and sulfate salt wastes on strength characteristics of aerated concretes. As shown in Fig. 3, adding salt wastes allows to improve the strength of aerated concrete during all periods of concrete hardening.

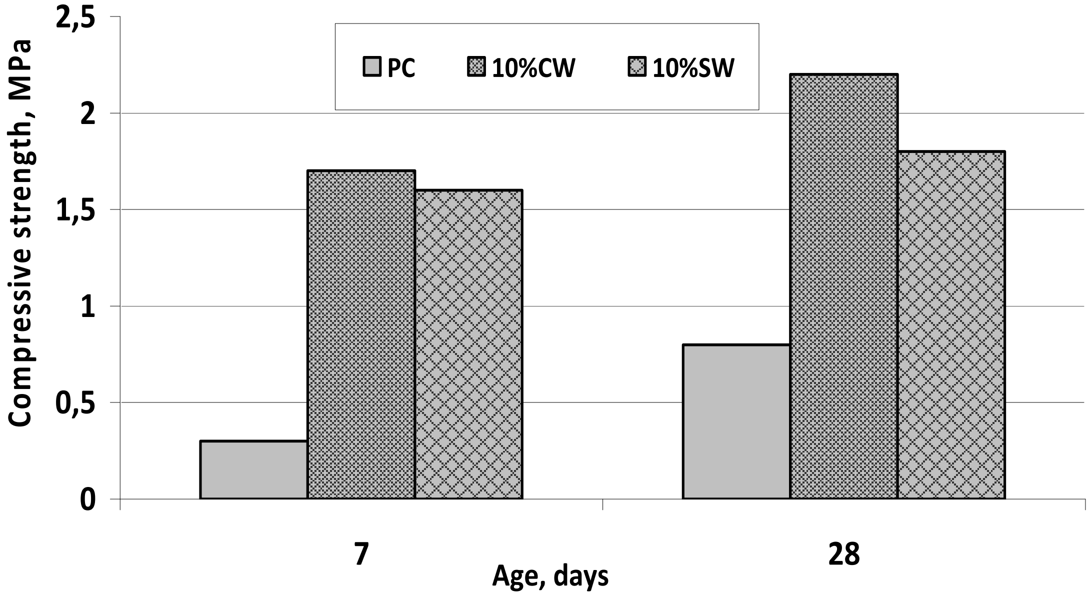
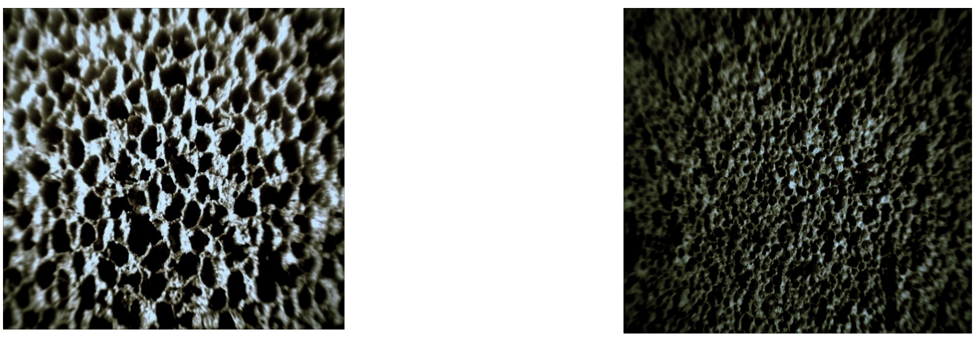


Fig. 3. The effect of salt processing wastes on compressive strength of aerated concrete

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.

With optical microscopy it was discovered that when ordinary Portland cement is used as a binder, the prevailing pores have the size of 1.1-2.2 mm, the number of them reaching 61%. When the modified cementitious system including carbonate-containing salt wastes is used, it can be observed that the number of tiny pores having the size of 0.2-1.0 mm increases from 23.5 % to 76.4 % (Fig.4).



A B

Fig. 4. Porous structure of aerated concretes based on Portland cement (A) and a modified cementitious system (B)

By the method of scanning electron microscopy it is revealed that there are carbonate crystals, plastic crystals of calcium hydroaluminates, and hydrocalumite (HC) in the structure partitions between pores of non-autoclaved aerated concrete which includes carbonate-bearing salt wastes (Fig.5). The presence of these crystals in the structure of aerated concrete facilitates compression of microstructure of partitions between pores and this causes increase in strength characteristics of the finished products. Thickness of partitions between pores is 0.16 – 0.21 mm.

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 SO_3^{2-}. 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%.

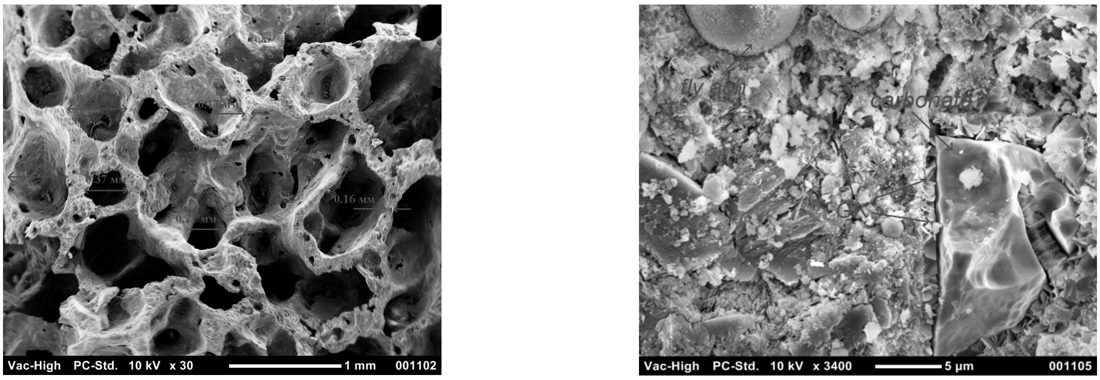


Fig. 5. Microstructure of partitions between pores of aerated concrete based on modified cementitious systems containing carbonate-bearing salt wastes

Regardless of the adopted technology, as well conditions and modes of hardening, the traditional drawbacks of aerated concretes are low resistance to tensile stresses and increased fragility. Non-autoclaved aerated concretes are characterized by high shrinkage strains, leading to intense fracture formation and even destruction of products [5]. Fiber reinforcement significantly reduces or completely eliminates the appearance and development of shrinkage cracks during hardening and further use of the material.

Experimental studies prove that introduction of the polypropylene fiber into aerated concrete does not affect kinetics of concrete array swelling (Fig.6). Thus, swelling multiplicity of aerated concrete without any reinforcing component in its composition is 2.83, whereas the aerated concrete mix containing 0.1 kg of polypropylene fiber is characterized by swelling multiplicity of 2.78. Increase of the fiber content does not affect kinetics of gas release and growth of aerated concrete array.

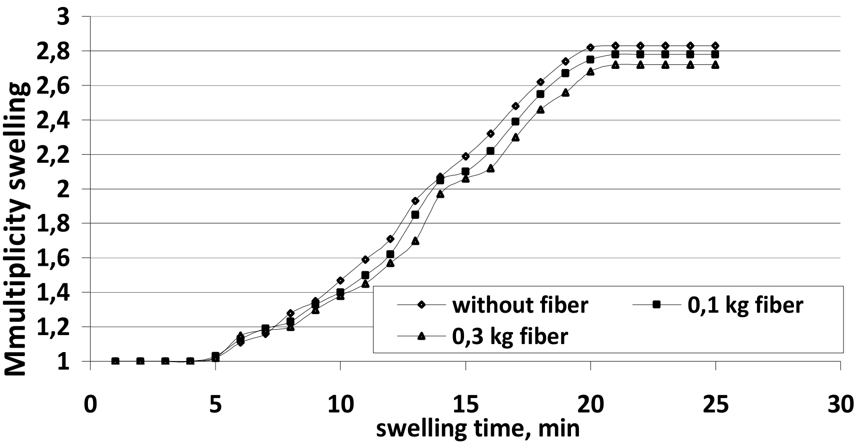


Fig. 6. Impact of polypropylene fiber on the kinetics of aerated concrete array swelling

The results of experimental studies show (Fig. 7) that introduction of reinforcing fibers into the composition of aerated concretes based on modified cementitious systems containing additional cementitious materials in the form of salt processing wastes enhances the strength of non-autoclaved aerated concretes.

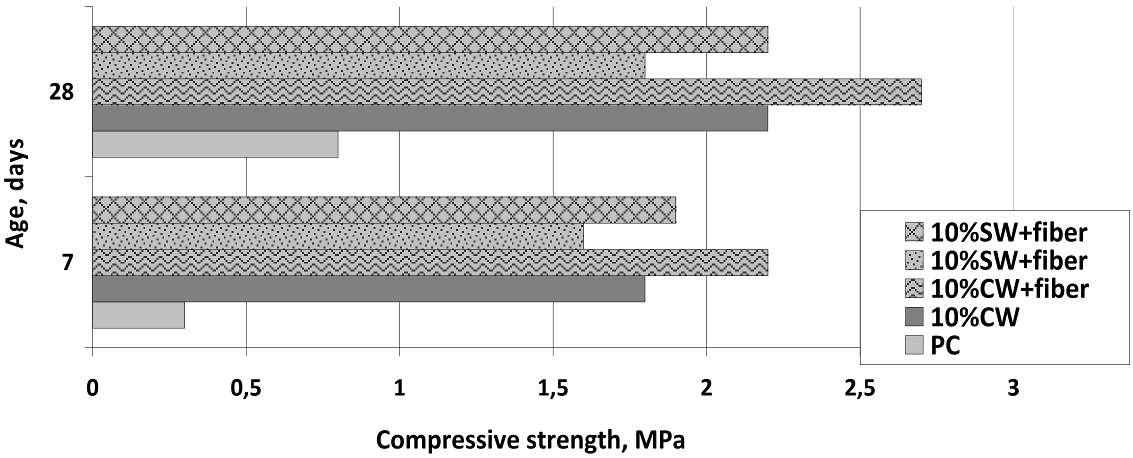


Fig. 7. Effect of polypropylene fiber inclusion on the strength characteristics of aerated concrete

After 28 days of hardening the strength of aerated concrete containing carbonate-bearing salt wastes with the inclusion of polypropylene fiber increases from 2.2 MPa to 2.7 MPa, whereas the strength of such concrete containing sulfate salt waste increases from 1.8 MPa to 2.2 Mpa, respectively.

Conclusions.

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. Including up to 10 wt. % of carbonate-bearing salt wastes into composition of cementitious systems causes increase of cement stone early strength as well as that of later terms of hardening; and the use of sulfate-bearing wastes causes decline of mechanical strength at all terms of hardening. Aerated concretes containing carbonate-bearing salt wastes have better ability to retain gas, the evidence of which is shortening the time of aerated concrete array growth from 21 min. to 12-14 min. and increasing multiplicity of swelling from 2.8 to 2.9. Introduction of reinforcing components into the composition of aerated concretes, polypropylene fiber, in particular, improves the strength characteristics of aerated concretes. 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%.

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