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The Control of Building Composite Structure Formation Through the Use of Multifunctional Modifiers

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Abstract: The study of the environmental management, the use of natural and environmentally friendly man-made materials, the introduction of new, modern, energy-efficient and resource-saving technologies at the creation of construction materials is one of the major problems that appeared since, the mid of the XX-th century. The use of non-traditional raw clay as the component of inorganic dispersed systems in the production of construction composites allows you to justify theoretically and confirm experimentally the possibility of controlling the structure formation processes to produce materials with the desired properties by introducing into the raw mass of non-traditional clay rocks for construction industry. Using non-traditional raw clay as inorganic plasticizing systems in construction materials production, the transition from the traditional raw material is possible to obtain the composite materials based on natural multifunctional materials that will speed up the synthesis of new formations change their morphology and optimize the microstructure of cement compounds and thus will improve the performance of products. On the basis of a special clay material used as an organic plasticizer one may obtain efficient, energy-saving highly porous painted wall building materials with low energy consumption.

Key words: Inorganic plasticizer, clay rocks, nanodispersed raw materials, heat and humidity treatment, structure formation, building materials

INTRODUCTION

The study of the environmental management, the use of natural and environmentally friendly man-made materials, the introduction of new, modern, of energy-efficient and resource-saving technologies in the production of construction materials is one of the major problems that appeared since, the mid of the XXth century. The solution to this problem is possible through the creation of new closed technological schemes with a full use of all co-products at all stages of production, based on modern science and technology achievements.

The production of widespread silicate materials throughout the world is based on the conventional technology which uses autoclaving of products and lime and quartz sand are used as raw materials. However, it is difficult to obtain energy-efficient, high porous products using traditional raw materials, due to the low strength of adobe bricks and non-optimal matrix structure. The solution to this problem is based on a new approach to the technology of silicate material production, consisting in the transition from traditional raw materials to a composite binder using inorganic plasticizers promoting targeted synthesis of cementitious materials and the optimization of an optimal composite microstructure.

Modern analysis of this resource base research concerning the industry of building materials allows to justify theoretically and confirm experimentally the possibility structure formation control to produce materials with desired properties by introducing the clay rocks non-traditional for the construction industry in raw materials (Lesovik, 2014b; Lesovik, 2015; Lesovik, 2014a; Volodchenko *et al*., 2014; Ali, 2011; Kiliaris, 2010; Emery *et al*., 2003; Howell *et al*., 1997; Mollins *et al*., 1996; Akayuli *et al*., 2013; Patterson and Murray, 1983).

By using non-traditional raw clay as inorganic plasticizing systems, in production of construction materials the transition from the traditional raw material to the production of composite materials is possible on the basis of natural multifunctional raw materials that will speed up the synthesis of new formations will change their morphology and will optimize the microstructure of cementitious compounds and thus, will improve the performance of products (Lesovik and Chulkova, 2011;

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Table 1: Granulometric size composition of sand-clay rocks

Rocks	Sieve size (mm); Fraction content, pts. (wt.)% <0.1	0.1…0.05	0.05…0.04	0.04…0.01	0.01…0.005	>0.005
Clay sand	15.7	12.90	5.82	42.95	5.70	16.93
Loam no.1	0.55	20.72	18.58	21.15	7.49	31.51
Loam no.2	0.2	9.33	9.56	29.86	9.35	41.70

Table 2: Chemical content of sandy and clay rocks

Rocks	SiO_2 gen.	SiO_2 free	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	l. on I.	Amount
Clay sand	82.87	61.78	6.70	0.42	2.63	1.77	1.03	1.26	1.10	2.05	99.83
Loam no.1	73.0	38.05	10.4	0.72	3.60	2.32	1.32	1.86	1.29	3.95	98.46
Loam no. 2	65.1	35.12	12.5	0.77	4.36	3.21	1.64	1.93	1.74	5.76	97.01

Alfimova *et al*., 2014; Volodchenko, 2013; Alfimova *et al*., 2013; Alfimova and Shapovalov, 2013; Volodchenko, 2012; Suleymanova *et al*., 2013).

From the whole range of clay deposits industry uses only a fraction which corresponds the applicable legal and technical documents. Due to the use of non-traditional clay rocks in the manufacture of a wide range of composite binders and wall materials the transition from the traditional raw material is possible to obtain the composites based on natural nanodispersed raw materials that will accelerate the synthesis of new formations will change their morphology and will optimize the microstructure of a cementitious compound and accordingly will improve the physical and mechanical properties of products.

The species of this genetic type are widespread. However, a large proportion does not meet the applicable regulatory requirements to raw materials for the production of traditional building materials. At the same time, the material composition and the presence of thermodynamically unstable compounds help reduce the energy intensity for the production of effective building composites of a new generation. It is possible to choose such a raw material only because of its genesis, structural and textural characteristics and mineral composition.

The specificity of these rocks composition is the presence of thermodynamically unstable compounds such as mixed layer minerals, X-ray amorphous phase, finely divided poorly rounded quartz, the hydromica of imperfect structure, rarely Ca^{2+} montmorillonite and kaolinite. Such an inorganic plasticizer allows you to change the morphology of new formations, providing the optimization of cementitious compound structure and accordingly to improve the physical and mechanical properties of steam-cured silicate materials.

The multimineral composition of sandy-clay rocks and their thermodynamic instability determine the possibility of interaction with lime to form cementitious compounds under hydrothermal treatment without pressure and thus to produce wall silicate materials with low energy consumption.

MATERIALS AND METHODS

Main part: The purpose of this research is the study of clay rock influence as multifunctional modifiers on the structure formation processes in the system $CaO-SiO_2-Al_2O_3-H_2O$ within the terms of hydrothermal synthesis and the obtaining of effective wall building materials according to energy-saving technology.

Three most widespread aeolian-diluvial-eluvial Quaternary clay rocks were used on the territory of KMA. These rocks differed in composition and properties. The number of rock plasticity varies from 6 (sandy loam) to 11.5 (loam number 1 and 2).

Visually, the samples are unconsolidated brown rocks. The bulk of the pelitic fraction has a pelitic morphous microscale structure, unevenly colored with an organic matter and iron hydroxides. According to granulometric size composition (Table 1) and the number of plasticity clay sand may be described as a dusty one and the loam number 1 and 2 as a light and dusty. According to granulometric size composition and plasticity number clay sand may be described as a dusty one and the loam number 1 and 2 as a light and dusty. The chemical composition (Table 2) shows that the rocks have a high silica content and are classified as acidic ones. The rocks contain a large amount of free silica.

Quick lump lime of OJSC “Stroymaterialy” (Belgorod) was used as a lime component. Lime activity made 78.3%, the temperature of quenching made 97.5°C, quenching time made 4 min 30 sec.

The aim of the performed experiments is the development of composite contents with the use of inorganic plasticizing systems, providing an optimal structure formation and the production of products with high physical and mechanical properties.

Table 3: Physical and mechanical characteristics of samples

	Lime content from dry compound mass (%)				
Physical and mechanical characteristics	5	10	15	20	25
Clay sand samples cast molding method					
Compressive strength (MPa)	2.23	2.73	2.79	2.50	2.23
Softening factor	0.81	1.00	0.88	0.97	0.87
Average density (kg m^{-3})	1510	1440	1390	1350	1285
Semidry pressing					
Compressive strength (MPa)	11.50	14.06	11.82	9.59	8.80
Softening factor	0.55	0.70	0.70	0.75	0.70
Average density (kg m^{-3})	1685	1670	1665	1589	1555
Compressive strength (MPa)	2.85	3.40	3.53	3.59	3.95
Softening factor	0.701	0.64	0.79	0.54	0.57
Average density (kg m^{-3})	1565	1460	1475	1400	1377
Semidry pressing					
Compressive strength (MPa)	9.13	14.38	15.35	16.52	14.19
Softening factor	0.68	0.71	0.785	0.73	0.54
Average density (kg m^{-3})	1715	1655	1660	1600	1556
Clay samples Cast molding method					
Compressive strength (MPa)	1.81	2.84	4.10	3.06	3.39
Softening factor	0.43	0.76	1.02	1.01	0.82
Average density (kg m^{-3})	1415	1397	1346	1286	1260
Semidry pressing					
Compressive strength (MPa)	7.39	13.79	13.02	11.08	11.27
Softening factor	0.61	0.70	0.79	0.75	0.88
Average density (kg m^{-3})	1540	1534	1505	1431	1455

The presence of nano-dispersed particles of aluminosilicate in the sandy loams and clay loams and fine dispersed active quartz in an alkaline medium leads to the formation of tobermorite hydrosilicates with various bases and calcium hydroaluminosilicates. At normal temperatures, these reactions are slow but they are accelerated considerably at elevated temperatures and humidity. These compounds have higher cementitious properties than, for example, $CaCO_3$ and Ca $(OH)_2$. Their water resistance and resistance to frost have a relatively large value.

Thus, the fine dispersed part of a clay rock plays the role of an active hydraulic additive and lime in this case is converted spontaneously into a hydraulic binder. Under the conditions of high temperature during a hydrothermal treatment the processes of cementitious compounds formation that occur at the interaction of lime and clay minerals are accelerated significantly which provides higher physical and mechanical properties for building materials.

Samples were prepared by injection molding process and semidry compaction. Pre-crushed limestone and the studied rock were mixed in a predetermined ratio, moistened with a necessary amount of water and cured in a sealed chamber until full slaking. The content of lime in the limestone-clay mixture was 5, 10, 15, 20 and 25 wt. %. The molding humidity of molding mixture, depending on the lime content ranged from 40-55%, the corresponding humidity of semidry pressing made 10-12%. The pressing was carried out at the pressure of 20 MPa. Samples were steamed at 90-95°C for 12 h. The results are shown in Table 1.

According to, the obtained data the samples of cast molding method based on clay sand have the maximum strength of 2.73-2.79 MPa when the content of lime makes 10-15 wt. %. Then, the strength is reduced. The samples of all compositions have a high water resistance. Softening coefficient is in the range above 0.81-1.00.

The strength of the samples based on clay sand increases from 2.85-3.95 MPa. However, the highest water resistance is presented by the samples with 15 wt. % of lime (softening coefficient makes 0.79). Maximum strength (4.1 MPa) and water resistance (softening coefficient of 1.02) is provided by 15 wt. % of lime and on the basis of clay. The average density for all studied clay rocks decreases with lime content increase and it is within 1260-1560 kg m^{-3} (Table 3).

The strength of semidry pressing samples is substantially higher than the cast ones. For sandy loam, the maximum strength of 14.06 MPa corresponds to lime content of 10 wt. %. For loam the most significant increase in strength from 9.13-14.38 MPa, occurs with the change in lime content from 5-10 wt. %. Further, the strength increases insignificantly and reaches the maximum from 16.52 MPa to 20 wt. % of lime. The highest strength for clay makes 13.79 MPa. It is achieved with the lime content of 10 wt. %. According to the numerical value of the softening ratio the samples with 10-20 wt. % of lime are water-resistant.

RESULTS AND DISCUSSION

The comparison of strength characteristic changes for all studied clay rocks indicates that in almost all cases,

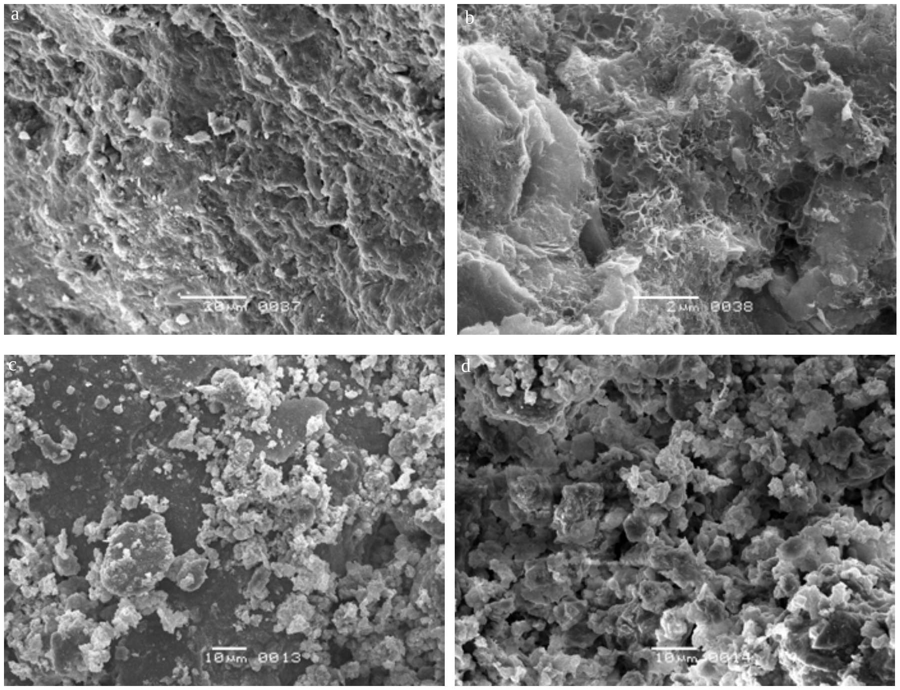

Fig. 1: The microstructure of steamed samples: a, b) Cast molding method based on sandy loam with the content of 10 wt. % of lime; c, d) Semidry compaction based on clay with the content of 20 wt.% of lime; a×1000; b×1300; c×1000; d ×9500

the samples obtain its maximum strength with the lime content of 10-15 wt. %. At that at 10 wt. % of lime the numerical values of strength are almost identical. For the samples of cast molding process on the basis of sandy loam, clay loam and clay, they make, respectively, 2.73, 3.40 and 2.84 MPa, for semidry pressing method they make 14.06, 14.38 and 13.79 Mpa. The samples with 15 wt. % of lime also have similar strength values.

The studied clay rocks significantly differ in material composition. However for all these rocks an optimum lime content makes 10-15 wt. %. It is of practical importance, since at the vibrations of raw material composition which are inevitable in the process of actual production, you can get construction materials with desired physical and mechanical properties.

The decorative properties of silicate materials include material color, the state of the front surface and the clarity of the faces from a textured layer. The samples based on sandy loam attain a light brown color which is not changed practically at heat and humidity treatment.

One of the important factors in the production technology of silicate materials obtained by dry pressing is the strength of adobe bricks. In the production of sand-lime silicate brick, the compressive strength of adobe bricks is usually in the range of 0.4-0.5 MPa. However, this strength is not enough to eliminate completely the defects in the process of product formation and transportation. Besides, it is difficult to obtain high-frequency products at such strength of adobe bricks. The strength of the adobe bricks at the use of raw clay as an inorganic plasticizer is in the range 1.10-1.25 MPa depending on lime content, that 2.5-2.75 times >the strength of lime-sand materials. This will greatly facilitate the issue of energy saving highly porous products.

The obtained physical and mechanical properties of silicate samples indicate that the studied materials in steaming conditions at the temperature of 90-95°C actively cooperates with lime. At that physical and chemical processes flow that lead to the synthesis of complex binder forming a solid frame. According to the data of differential thermal and X-ray analyzes the new formations are presented mainly by weakly crystallized calcium hydrosilicate compounds CSH (B) and C_2SH_2 Calcium hydrosilicates are formed mainly due to the interaction of lime with metastable clay minerals of nanoscale level. During the interaction of calcium hydroxide with clay minerals under the conditions of heat and humidity treatment the bonds between silicon-oxygen tetrahedrons weakening and aluminum atoms in the crystal lattice of a clay mineral and alumina and silica acquire the ability to react with calcium hydroxide. The reaction products are calcium hydrosilicates and the hydrogarnets from a series of solid solutions C_3AH_6-$C_3AS_2H_2$. The synthesis of hydrogarnets is confirmed by the appearance on reflection X-ray within 271-281 Å.

The microstructure of steamed cast molding samples based on sandy loam and compressed on the basis of clay, containing 10 and 20 wt. % of lime, respectively, is shown on Fig. 1.

The sample on the basis of sandy loam due to excess water demonstrate loose, matrix structure (Fig. 1a, b) which is associated with a large excess of water during the preparation of material. Due to this, the samples have a low average density and high water absorption. However, the high values of softening ratio for the obtained samples evidence about the obtained structure stability of the cementitious compound to the water. A condensation-crystallization structure is developed here most likely.

Denser structure of new formations is developed in the molded samples (Fig. 1c, d). In a clay-based sample new formations presented by weakly crystallized low-basic hydrosilicates of calcium, forming a grid are filled with anisotropic pores between the relic structure of clay material condense it and create a more dense material. In this case, a crystallization structure is developed.

The strength of the resulting material structure is influenced significantly by micro filler grains presented by sand particles and their contact area is with the bulk. The investigated rock, as indicated above, contains mainly the sharp-edged quartz particles the surface of which is corroded in varying degrees. These quartz particles are virtually indistinguishable in a dense matrix of substance new formations based on lime and fine parts of the rock. By increasing the packing density of the material which gives a higher average density for a product and compressive strength a stronger material microstructure is achieved.

Summary: During the use of non-traditional clay rocks as inorganic plasticizing systems a solid microstructure of cementitious material is developed due to the high packing density of the material as well as the number of contacts and their strength increase between new formations as the result of hydrogarnet synthesis that are the microfillers in submicrocrystalline gel phase of low basic calcium hydrosilicates. Thus, high physical and mechanical properties are provided.

CONCLUSION

Thus, we have proved the possibility of synthesis in the system of CaO-SiO_2-Al_2O_3-H_2O new formations without traditionally used worldwide autoclaving at 0.8-1.2 MPa. The examined unconventional raw clay due to metastable nanoscale clay minerals contained therein actively reacts with lime in a heat and humidity treatment at the temperature of 90-95°C to form low basic weakly crystallized calcium hydrosilicates and hydrogarnets that lead to the appearance of a strong coagulation-crystallization and crystal structure of the material, providing high physical and mechanical properties of silicate products. On the basis of non clay material used as an inorganic plasticizer one may receive an effective energy-saving highly porous painted wall building materials with low energy consumption.

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