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ENERGY SAVING RAW MATERIALS FOR THE PRODUCTION OF NEW GENERATION SILICATE MATERIALS

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Abstract.

The study of rational nature use issue, the use of natural and environmentally friendly man-made materials, the introduction of new modern, energy-efficient and resource-saving technologies during the creation of building materials is one of the most important problems, the solution of which is possible by the creation of new closed technological schemes with the full use of all coproducts during all production stages. It was found that one may use the depositions of clay formation process initial stage, which are composed of metastable minerals of imperfect structure, finely divided silica and amorphous structures as energy-saving raw materials for the production of new generation silicate materials with hydrothermal hardening. Due to metastable minerals and finely dispersed quartz the polymineral composition of neoplasms is synthesizeв and the formation of a cementitious compounds optimal microstructure is accelerated that allows to obtain the silicate materials with high physical-mechanical characteristics not only during autoclave treatment, but within steaming conditions at atmospheric pressure. Using the studied raw materials one can obtain effective colored highly porous silicate bricks and stones, as well as cellular concretes, the use of which will increase the comfort of human habitation in construction.

Keywords: energy saving materials, comfortable living environment, argillaceous rocks, hydrothermal treatment, silicate materials

Introduction: The most urgent task for modern building is the creation of a comfortable environment for a person that will not only meet the housing needs, but will also ensure a high quality of life in general. The triad "man-material-environment" is a complex system, the study of which requires the involvement of scientists from different fields. This line of research is the most important one in the XXI-st century [1-5].

Comfortable living environment must be considered from the point of view of security issues, including the basic parameters of sanitary conditions, fire safety. At the same time the basic minimum indicators per person are determined. The term "comfort" includes a set of household facilities, which include well developed and cozy dwellings, public buildings, communication means, etc.

In order to create a comfortable environment the cooperation of the whole complex of sciences is required, starting with the construction material science, medicine, architecture, etc., i.e., a transdisciplinary approach is needed. The system "man-material-environment" is a very complex open system, the study of which is possible with the use of transdisciplinary science - geonics.

Transdisciplinary studies are based on large-scale use and the transfer of knowledge, laws, cognitive schemes from one disciplines to the other with the obtaining of emergent properties - the properties which individual links (disciplines) do not have, but they are the result of a system integrity effect, which is especially important for construction material science and the creation of new generation materials [4-12].

The creation of an enabling environment for a man's life must be the goal of urban planning, architectural and construction activity. In order to create the aesthetics of living some quality architectural solutions are needed, such as landscape design, small architectural forms, the organization of court territories, lighting, fences, etc. The image of residential buildings provides the decisive influence on a city development and quarter building.

After the changes in the environment that appeared during recent years numerous studies appeared on environment state and its impact on human health. However, a city dweller spends most of his time indoors, and the environmental comfort there is more important for a man's health. Often, the concentration of pollutants indoor is greater than outside. In this regard we need a new paradigm to design and manufacture efficient building composites that provide comfortable living conditions, performance and a man's health.

The concept of "comfort" includes such basic components as microclimate parameters, noise, illumination, coloring, etc. It should be noted that at the loss of one main parameter at least 100% of comfort can be lost.

Environmental safety issues concerning the production of building materials, and the issues of materials become more and more important today. The materials used in construction, must not release toxic substances, the radiation level and environmental damage should be minimized during production process. Natural materials correspond to these criteria most of all. These materials include first of all wood and stone, as well as the products made from natural raw materials - concrete, brick, glass and others. Such products are of high quality and safe for a man's health. Autoclave silicate materials are among the most economical and common wall materials (Fig. 1).

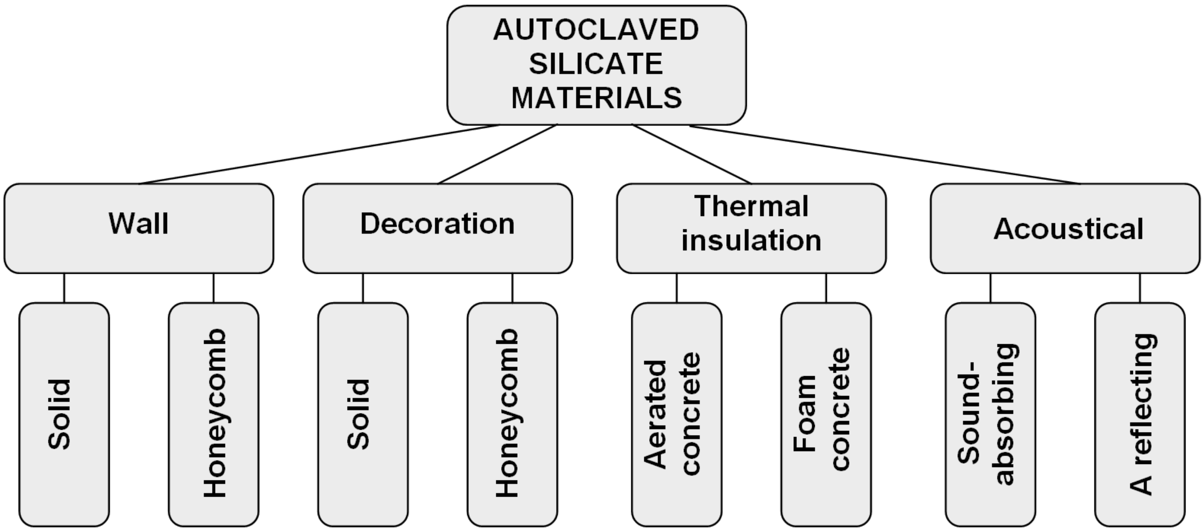


Fig. 1. Classification of autoclave silicate materials.

Environmentally friendly materials are the raw materials for their production: mineral binder, siliceous component and water. Portland cement and ground lime are used as a binder. The replacement of lime and Portland cement (metallurgical, fuel and others) by milled slag is possible. During autoclaving at the temperature of 174-180 °C the organic impurities accidentally caught in a mixture, are burned out and disappear. Therefore, such products do not emit harmful components during the operation at various internal and external influences.

Autoclave materials and products can have a dense and mesh structure. The materials of dense structure include the slabs made of hard silicate concrete, wall panels and floors, large silicate blocks, as well as the most common wall material - sand-lime brick. Sand-lime brick is produced as a corpulent one or in a lightweight version with half-closed voids.

The advantage of porous concrete is a low average density and low thermal conductivity, a relatively high strength and frost resistance. Aerated concrete is characterized by increased water vapor permeability, which allows material to derive excess moisture from the inner space of a building, so that mold and mildew can be avoided in gaseous concrete wall. According to its hygienic properties aerated concrete can occupy the second place after wood.

According to the cost-effectiveness during the use of load-bearing walls in the construction of residential buildings aerated concrete blocks are superior to such materials as hollow brick, ceramsite concrete, aerated concrete and wood.

The analysis of the data on the research material resource base of an autoclave hardening allowed to justify theoretically and confirm experimentally the possibility of sand use instead of clay rocks by an unfinished phase of mineralization processes. Similar clay rocks are widely distributed, and are extracted simultaneously in large quantities during the extraction of ore minerals. The specificity of these ores is the presence of thermodynamically unstable compounds, such as hydromica of imperfect structure, mixed layer minerals, poorly rounded finely dispersed quartz and a small amount of kaolinite and montmorillonite. These raw materials with the properties of natural nanoparticles allow you to control the synthesis of new formations in order to obtain the materials with desired properties.

Given that the natural processes carried out the part of the work on rock disintegration the process of rock-forming minerals interaction with an astringent component is possible not only at high pressure, but also at atmospheric pressure with the temperatures up to 100 °C.

Clay rocks are used as building materials since ancient times. Clay has a low thermal conductivity, and is favorable by the fact that it preserves comfortable indoor temperature even during heat. Besides, home clay is environmentally safe for the people living in clay houses.

However, clay products have low water resistance. Using clay rocks as raw materials one can combine the advantages of clay products and the autoclave silicate materials.

The aim of the paper is to obtain hydrothermal silicate materials of new generation on the basis of hardening clay rocks during an unfinished stage of mineralization.

Methods

The clay rocks of unfinished mineralization stage were used for studies. Quick lump lime with the activity of 83.4% was used as a binding component. The paper also used silica sand with the fineness modulus of 1.52, and the content of SiO_2 94.2 wt. %.

In order to obtain dense structure materials a raw mixture was prepared using lime-sand-clay binder, obtained by joint grinding of a rock and lime to the specific surface area of 350 m2/kg. The samples were prepared by semi-dry molding under the specific pressure of 20 MPa. Autoclaving was performed at a steam pressure of 1 MPa according to the following mode: the rise of vapor pressure made 1.5 hours, the isothermal curing made 3-4 h, the depressurization of steam made 1.5 hours. According to non-autoclave technology the samples were steamed in a steaming chamber at the temperature of 95 °C for 12 h.

In order to obtain aerated concrete the molding technology was used. High dispersion of clay rocks allows to eliminate their preliminary grinding during the obtaining of a raw mixture. Aluminum paste was used as a blowing agent. The samples of porous concrete were autoclaved at the saturated steam pressure of 0.6-1.4 MPa according to the following mode: steam pressure rise - 1.5 h, isothermal curing - 3-5 h, steam depressurization - 1.5 h.

Main part

Clay rocks have a very diverse mineral composition and properties. Thus, the features of a cementitious compound development were studied in the presence of clay minerals, which made it possible to develop the calculation methodology for a raw mixture composition based on a lime-clay binder. The basis of the proposed methods is the condition in which CaO content must make the amount necessary for a complete interaction with clay minerals contained in a binder.

During the interaction of clay rock forming minerals, including nano-dispersed clay minerals, calcium hydrosilicates are developed with lime with various bases and hydrogarnets are developed that promote the formation of a cementitious compound with a rational microstructure. It was found that the management of new formation synthesis is the most effective one due to the introduction of rocks containing clay minerals along with 40-70 wt. % of fine quartz.

The research results were tested using the raw material resources of RF and foreign countries. The technology of dense and cellular silicate materials obtaining with high physical and mechanical values was developed according to energy-saving technology (Table 1).

Table 1: Properties of autoclave silicate materials based on sand-clay rocks.

Autoclave silicate materials	Average density, kg/m^3	Compressive strength, MPa	Frost resistance, cycles	Thermal conductivity, W/(m·°C)
Dense	1900–2000	20–35	35–50	07–0,8
Thermal insulation	350–400	2,0–3,0	15	0,075–0,1
Constructional and heat-insulating	700	4,5–5,5	25	0,13–0,14

The reduction of energy consumption for production takes place due to the reduction of autoclave processing pressure at the reduction of isothermal holding time in an autoclave by 3.2 times, and lime consumption reduction is also possible. A high dispersion of the studied raw materials reduces the grinding period of a lime-sand-clay binder, and during the production of aerated concrete the pre-grinding of sand and clay raw materials exclusion is possible.

It was found that sand-clay rocks contribute to a raw product strength increase by 3-4 times, which will improve the formability of a raw mix, facilitate the release of highly porous products and will reduce waste in the process of development.

Aerated concrete has a good insulating capacity at high rates of resistance. Thermal resistance of residential and public building walls made of aerated concrete, fully comply with new SNIP requirements. The thermal conductivity ratio of aerated concrete on the basis of a lime-sand-clay binder in a dry state makes 0.08 - 0.10 W/m °C for thermal insulation materials and 0.14-0.15 W/m °C for construction materials. The thermal conductivity of these materials is lower than aerated concrete based on conventional materials. For control sand-lime images of aerated concrete these figures were 0.1 and 0.16 W/m °C respectively. This is related to the fact that the new formations of aerated concrete on the basis of a lime-sand-clay binder has a more complex structure and, accordingly, a lower thermal conductivity.

Aerated concrete has good thermal accumulation properties. The feature of a house built of aerated concrete is that the heating of its premises requires significantly less energy than for the premises made of brick walls. The costs for a house heating made of aerated concrete is reduced by 20-30%.

Despite the highly porous structure, aerated concrete is not a hygroscopic one. The equilibrium moisture content of aerated concrete walls is in the range of 5-6 wt. %. The same index is 4 times higher for wood walls. Aerated concrete contains the pores of an open and a closed type. Due to this the moisture absorption occurs only at a small depth.

The presence of closed pores prevents the penetration of moisture deep into the material. At low temperatures water increasing in volume, does not lead to the formation of cracks, since it is distributed in open pores during freezing.

Aerated concrete is characterized by a predominantly open pores that allow the penetration of air, so the walls "breathe", which improves the climate comfort in a house made of aerated concrete.

On the basis of the proposed raw materials the acoustic materials can be obtained. The presence of interconnected pores of an open structure leads to a high sound absorption capability of aerated concrete. They provide active sound insulation requirements in the buildings made of aerated concrete. According to the official rules this index should be at least 41 dB for residential premises.

One way for the creation of new generation construction composite is the development of wall materials for "green" construction through the use of aluminosilicate raw materials of different genetic types.

The selection of such a raw material is possible only because of its genesis, structural and textural characteristics and mineral composition.

Geological processes disintegrate rocks, make its particles more amorphous and create structural defects, which significantly increases the activity of raw material (Fig. 2).

The improvement of physical and mechanical properties of silicate materials and the reduction of their power consumption can be achieved by the obtaining of hydrogarnets within the composition of a cementing compound and other compounds of $CaO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O$ system.

The data analysis concerning the study of raw material base for autoclave materials allowed to justify theoretically and confirm experimentally the possibility of new formation synthesis control to obtain the materials with desired properties by the introduction of clay rocks of a clay formation unfinished stage into a raw mass.

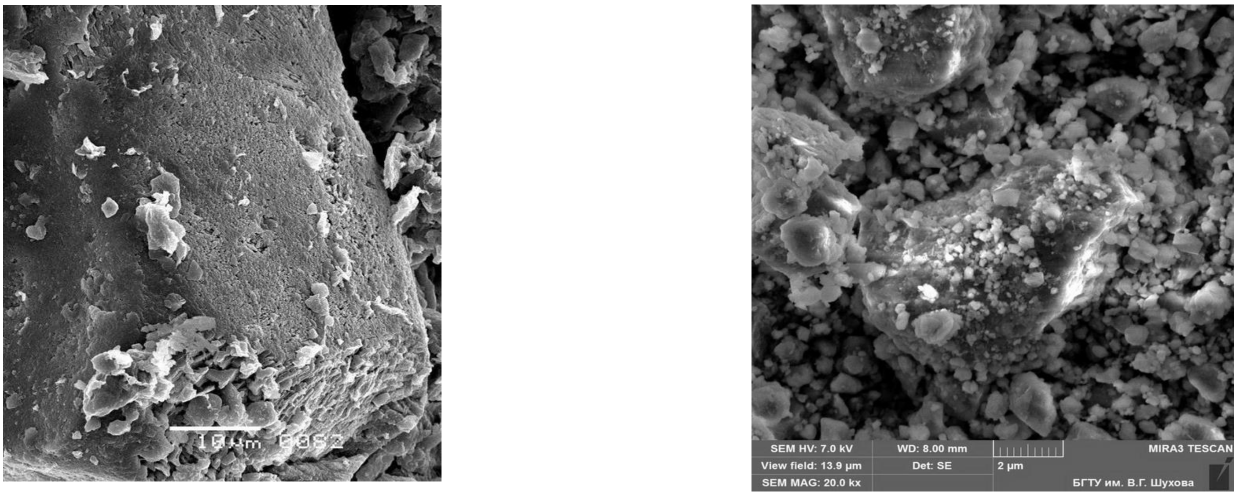
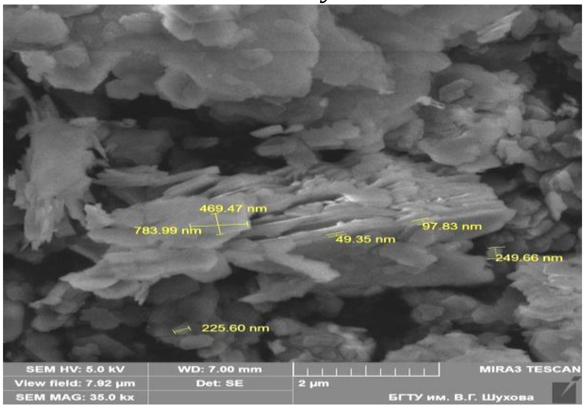


Fig. 2. Quartz surface disintegrated by geological processes

Rock-forming minerals of clay rocks allow to change the morphology of crystal new formations, ensuring the optimization of cementitious compound structure and, consequently, improving the physical and mechanical characteristics of autoclave silicate materials.

The clay material has a complex chemical and mineral composition [14-24]. In recent decades the structure of clay minerals and their properties were studied in detail using the modern research techniques (electron microscopy, X-ray diffraction analysis, infrared spectroscopy). It was found out that the elementary layers and the spaces between them are in a clay system are nanoscale ones and have highly active surface. If we separate nanocrystals from each other by a physical or a chemical means, a universal modifier will be developed, the distance between its plates makes about 1 nm (Fig. 3).



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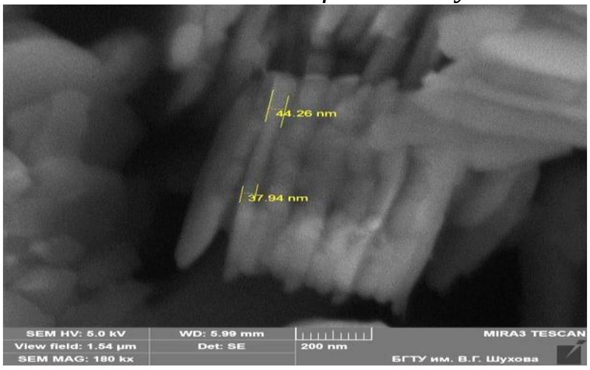

б)

Fig. 3. The layers of clay material flat nanocrystals, SEM:

а) — ×35000; б) — ×180000

Thus, it can be concluded that the obtaining of effective silicate materials is possible under hydrothermal treatment without pressure by using aluminosilicate rocks of clay formation incomplete stage as a raw material, the composition of which is characterized by a thermodynamically unstable compounds.

Three eolian-diluvial-eluvial clay rocks of Quaternary age most common on the territory of the Kursk magnetic anomaly were used, which differ in composition and properties (Table 1). The number of rock plasticity varies from 6 (sandy loam) to 11.5 (loam №1 and loam №2).

Table 2. Granulometric composition of sand-clay rocks.

Rock	Sieve size, mm					
	< 0,1	0,1…0,05	0,05…0,04	0,04…0,01	0,01…0,005	> 0,005
	Fraction content, wt. %					
Sandy loam	15,7	12,90	5,82	42,95	5,70	16,93
Loam № 1	0,55	20,72	18,58	21,15	7,49	31,51
Loam № 2	0,2	9,33	9,56	29,86	9,35	41,70

Ground lime and lime-and-sand-clay binder (LSCB) obtained by the co-grinding of lime and rock were used as a binder. The ratio of lime: LSCB sandy loam was 1:2, specific surface area made 770 m^2/kg. The raw mixtures were prepared by the mixing of a used binder with an original rock. The lime content in raw material mixtures varied from 4 to 14 wt. %. The samples were formed from the raw mixture with 10% humidity at a compression pressure of 20 MPa, which was taken in a traditional sand-lime brick production technology.

The durability of raw material based on lime-sand (control) mixture made 0.43 MPa. The use of a sand-clay rocks as a silica component substantially increases raw rock strength. At that the strength increases with lime content increase (Fig. 4).

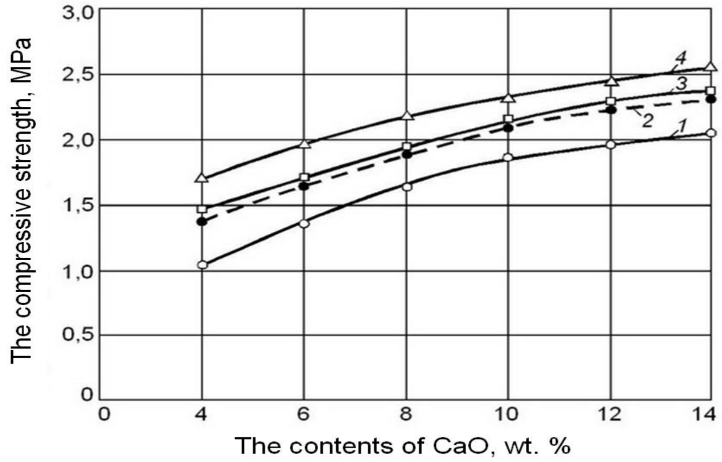

Fig. 4. The effect of lime content on raw material strength. Rock: 1, 2 - sandy loam; 3 - loam number 1; 4 - loam number 2; Binder: 1, 3, 4 - lime; 2 - LSCB

The use of sandy loam as a silica component at lime content of 10 wt. % allows to obtain a raw material with the strength of 1.85 MPa, which is higher than the strength of control samples 4.3 times (Fig. 4, curve 1). The strength of a raw material on LSCB basis (lime content makes 10 wt.%) increases 4.9 times (Fig. 4, curve 2).

Loams provide higher strength of a raw material than a sandy loam (Fig. 4, curves 3 and 4). This is due to an increased content of pelitic fraction. The increase of strength for loam number 1 and number 2 at the lime content of 10 wt. % makes 5.1 and 5.5 times respectively. In order to evaluate the effect of water action on the strength properties of the obtained material the samples of each composition were held for 1 year in tap water. The results are shown in Table. 2 and on Fig. 5.

Table 2: Physical-mechanical characteristics of samples on clay sand basis.

Physical-mechanical characteristics	Lime content, wt. %				
	5	8	10	12	15
Compressive strength, MPa	17,80	18,60	22,58	17,50	16,70
Compressive strength of water saturated samples, MPa	14,00	14,4	18,35	17,46	15,73
Softening factor	0,79	0,78	0,81	0,99	0,94
Average density, kg/m3	1880	1855	1850	1815	1755
Water absorption, %	13,03	13,20	13,85	14,26	16,76
The compressive strength of water saturated samples after the storage in water for year, MPa	22,10	25,24	28,10	34,71	29,45

The increase of lime content from 5 to 10 wt. % increases the sample strength from 17.8 to 22.58 MPa (see Fig. 5, curve 1). The increase of lime content up to 15 wt. % reduces the strength up to 16.7 MPa. The maximum strength of samples in water-saturated condition (18.35 MPa) also corresponds to the lime content of 10 wt. % (see Fig. 5, curve 2). The softening ratio makes 0.78-0.99, which demonstrates a high water resistance of obtained material (see Table 2). The average density with lime content increase decreases from 1880 to 1755 kg/m^3, the water uptake increases from 13.03 to 16.75 %. The test results of water saturated samples aged during 1 year in water, showed a significant strength increase as compared with water-saturated samples that were not subjected to long-term storage in water (see. Fig. 5, curve 3). The samples achieve the maximum strength of 34.71 MPa with the lime content of 12 wt. %. At that the strength, as compared with the samples without a long-term storage in water increased twofold (see Table 2). This is related to the fact that the rock forming minerals and, in particular, its nanoscale component provides the synthesis of cementitious compound with hydraulic properties.

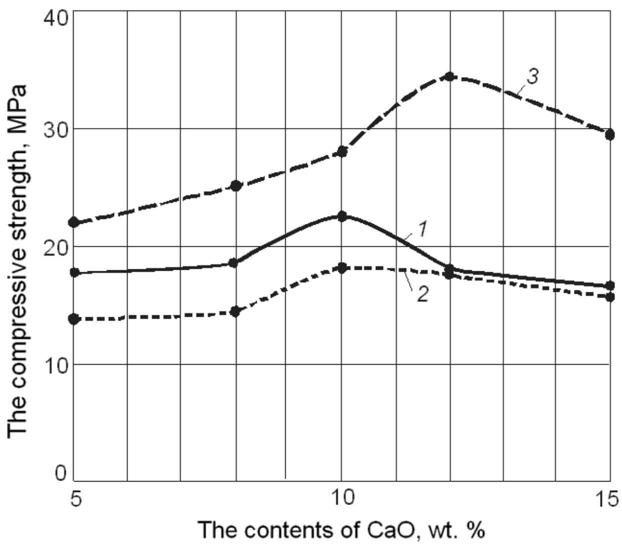

Fig. 5. The compressive strength limit of the samples according to lime content:

1 - samples after 2 days of curing at room temperature;

2 - water saturated samples;

3 - water saturated samples after storage in water

The obtained sand-clay rocks have different colors depending on their mineral composition, thereby making it possible to obtain bodily colored silicate materials. The production of highly porous colored silicate brick allows to improve its market competitiveness significantly among building materials. Due to the volumetric painting one can also use crushed brick for a front masonry with a quarry stone surface. Smooth ashlaring in conjunction with laying of crushed colored silicate brick will create a special architectural expressiveness for residential and public buildings.

Summary

Thus, one can use the depositions of mineralization process initial stage, which are composed of metastable minerals of imperfect structure with nanodispersed level, fine quartz and amorphous minerals as an energy-efficient raw material for the production of autoclave silicate materials that will improve the physical and mechanical properties of autoclave silicate materials. The replacement of traditional materials by stripping sand-clay rocks will reduce the content of waste in dumps, improve the environment and expand the raw material base for autoclave silicate material production. The performance characteristics of building materials based on the clay rocks of an unfinished stage of lithogenesis and the heteroporosity on nano-, micro- and macro-level contributes to the creation of a comfortable environment in residential units, which can significantly increase a human lifespan. Theoretical and practical approaches should be the prerequisite for the creation of a new class of "smart" construction materials with advantageous properties [25-35].

Conclusions

The possibility of deposit use during the initial stage of mineral development processes as an energy-efficient raw material for the production of silicate materials with hydrothermal hardening of the new generation. Due to metastable rock minerals they synthesize the polymineral composition of rock and accelerate the formation of a cementitious compound optimal microstructure that allows to obtain silicate materials with high physical-mechanical characteristics within the terms of autoclaving, and the terms of steaming at atmospheric pressure. With the use of studied raw material one can obtain effective highly porous colored silicate bricks and stones, finishing materials, cellular concretes and acoustic materials, the use of which in the construction will increase the comfort of human habitation. The reduction of energy consumption for the production of a new generation of silicate materials makes 30-40% in comparison with the conventional technology. ** This article was prepared as part of the research project RFBR №14-41-08002 «Theoretical Foundations of design and creation of intellectual composite materials with desired properties»*

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