Scientific and Theoretical Fundamentals of Alumina-silicate Binding Agent Design on the Basis of Technogenic Raw Materials Used to Produce Non-autoclaved Silicate Materials

Scientific and Theoretical Fundamentals of Alumina-silicate Binding Agent Design on the Basis of Technogenic Raw Materials Used to Produce Non-autoclaved Silicate Materials

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Abstract. These days the use of natural and technogenic raw materials is particularly relevant for the production of efficient construction composites, including the use of nature-like technologies. Successful development of efficient compositions of raw mixes using technogenic and natural raw materials of various genesis is only possible on the basis of in-depth and versatile study of physical, chemical and technological solidification. Thus, the use of nonconventional alumina-silicate raw materials during the production of construction composites provides for theoretical and experimental possibility of shifting from traditional raw materials to the production of composite materials on the basis of nonconventional natural and technogenic raw materials. The study resulted in scientific and theoretical fundamentals of alumina-silicate binding agent design on the basis of technogenic raw materials used to produce non-autoclaved silicate materials. It is suggested to use alumina-silicate rocks of incomplete stage of clay synthesis as an active component of non-autoclaved silicate materials, which structure differs with regard to their thermodynamically-unstable compounds, which, in turn, may result in the production of efficient energy-saving high-hollow silicate materials of a new generation with up to 32 MPa compression strength, F15-25 frost resistance and 1100-1200 kg/m^3 average density.

1. Introduction

One of the most critical problems of the present is the creation of breakthrough technological solutions in the field of energy saving, rational environmental management, environmentally friendly production of construction materials, which corresponds to current trends of 'nature-like' technologies ensuring preservation of the environment and creating favorable conditions for human life. Due to achievements of construction materials science, a considerable change of produced construction materials is expected in the next 10-20 years. Hence, further formation of construction materials science, development of mining industry and geological features of the Russian Federation provoke the search of new types of raw materials meeting the demands of geological and technogenic processes contributing to the production of construction materials. Currently, western production technologies of construction materials, which do not suit raw material resources and climatic conditions of the country are being implemented in the Russian Federation. However, their use is still doubtful in respect to durability and ecological safety.

The use of natural and ecologically safe nonconventional multifunctional alumina-silicate raw materials during the creation of highly efficient and ecologically safe construction materials of a new

generation, as well as technologies of their production able to maintain the balance between the 'biosphere' and the 'technosphere' remains one of priority development areas in construction industry of the Russian Federation. The study of raw materials within autoclaved hardening provided for theoretical and experimental confirmation of a possibility to use incomplete phase of mineralogenesis processes instead of clay rock sand.

Such clay rocks are widespread and extracted in large volumes during ore minerals development. The specifics of such rocks includes the existence of thermodynamically unstable compounds such as alternating-layer hydromicas, finely dispersed poorly rounded quartz, as well as montmorillonite and kaolinite in small quantities. These raw materials with properties of natural nanoparticles allow managing the synthesis of new growths in order to obtain tailored materials [1-6]. Considering the fact that natural processes have completed a part of work related to the disruption of rocks, the interaction of rock-forming minerals with the binding component is possible not only at high pressure but also at the atmospheric pressure under the temperature of up to 100 °C. The studied raw materials make it possible to receive efficient painted high-hollow silicate bricks and stones, as well as cellular concrete, which use in construction will ensure comfortable living conditions.

2. Materials and methods

Hard-burned lump lime of JSC Belgorodstroymaterialy (GOST 9179-77) was used as the binding component. Aeolian eluvial deluvial clay rocks of the Quarternary age of the Kursk magnetic anomaly fields were used in the study.

The MicroSizer 201 installation, which allows determining the size of particles ranging from 0.2 to 600 microns, was used to define the particle size distribution of materials.

X-ray phase analysis was used to study the mineralogical composition of raw materials and synthesized new growths. The study was conducted via X-ray diffractometer ARL X'TRA Thermo Fisher Scientific. Besides the X-ray phase analysis, the differential thermal analysis was used to identify products of new growths and mineral composition. The study was conducted via Derivatograph Q – 1500 D. Microscope MIRA 3 LM was used for scanning electron microscopy (SEM).

The production of samples depended on the raw mix composition. If a ground hard-burned lump lime was used as a binding agent, the mix was prepared by mixing of raw components in necessary proportions.

The mix, which included previously prepared binding agents (earlier ground clay rock and the binding component), was mixed with the base rock or silica-containing component with the same composition, and then was moistened with water. After molding the samples were placed in the steam chamber and were exposed to steam curing at a temperature of 90-95 °C as follows: 1.5h + 9h + 1.5h.

3. Main part

At present, there is an urgent need to increase the production and expand the use of wall materials combining high constructive, decorative and operational qualities with rather low cost. There is a tendency towards eco-friendly materials produced from processed raw materials or wastes, which leads to material low cost. One of the methods to create the construction composites of a new generation is the development of wall materials for construction using alumina-silicate raw materials of various genetic types, including with the use of nature-like technologies [6-8].

It is possible to choose such raw materials only taking into account their genesis, structural and textural features and mineral composition [9-13]. Geological processes disintegrate rocks, amorphize their particles and create structural defects, which considerably increase the activity of raw materials (Figure 1).

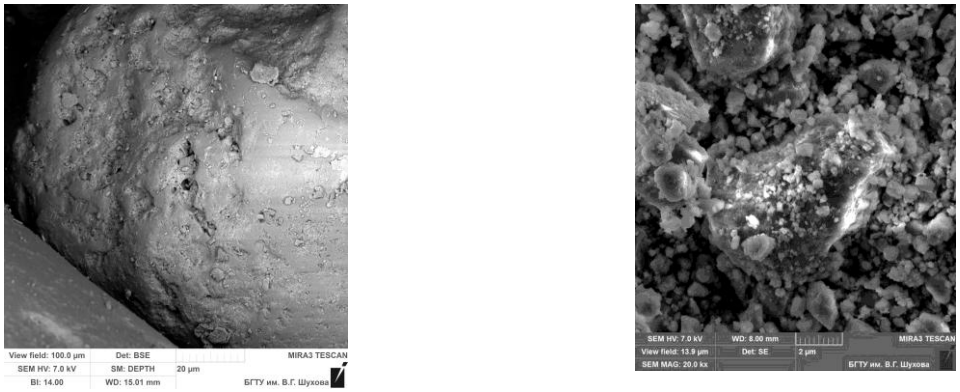


Figure 1. Surface of quartz disintegrated through geological processes.

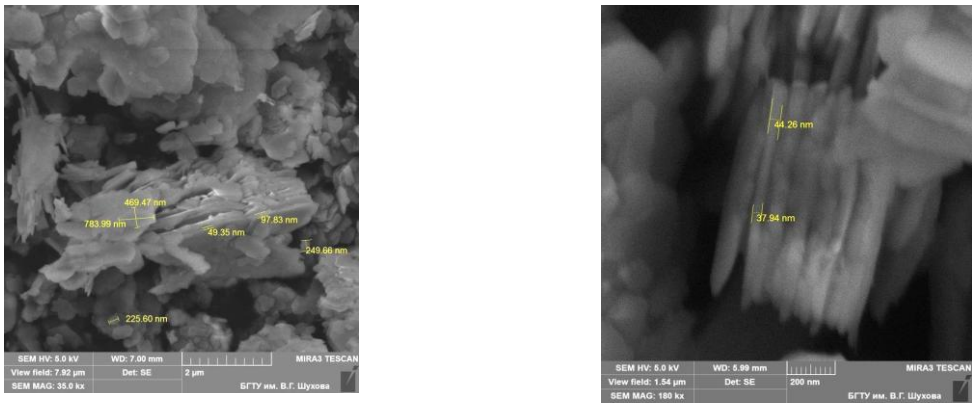
The improvement of physical and mechanical properties of silicate materials and the decrease in their energy consumption may be achieved by adding hydrogarnet and other compounds of the $CaO–Al_2O_3–SiO_2–H_2O$ system into their cementing composition.

The study of autoclaved raw materials provided for theoretical and experimental confirmation of a possibility to manage the synthesis of new growths in order to obtain materials with tailored properties by introducing the raw mass of clay rocks of an incomplete stage of clay synthesis of various genetic types.

Rock-forming minerals of clay rocks allow changing the morphology of crystal new growths that ensure optimization of cementing composition and, respectively, improve physical and mechanical properties of autoclaved silicate materials.

Clay matter has complex chemical and mineral composition. In recent decades with the use of modern methods of study (electronic microscopy, X-ray diffraction analysis, infrared spectroscopy) the structures of clay minerals and their properties were studied in detail. It was found that the elementary layers and spaces between them within a clay system are nanodimensional and have highly-developed active surface. The separation of nanocrystals from each other through physical or chemical methods leads to the universal modifier with the distance between plates of about 1 nanometer (Figure 2).

Thus, it is possible to conclude that alumina-silicate rocks of incomplete clay-formation stage, which structure is characterized by thermodynamically unstable compositions, used as raw materials ensure the production of efficient silicate materials in the conditions of hydrothermal processing under pressureless conditions.



a) b)

Figure 2. Layers of flat clay nanocrystals, SEM:
a) — ×35000; b) — ×180000.

Three aeolian eluvial deluvial clay rocks of the Quarternary age, which have different composition and properties and are widely spread throughout the Kursk magnetic anomaly (Table 1) were used as the object of study to confirm theoretical fundamentals. The plasticity index of rocks changes from 6 (sandy loam) to 11.5 (loam 1 and loam 2).

Table 1. Particle size distribution of sandy and clay rocks.

Rock	Mesh 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

The ground lime and alumina-silicate binder (lime and sand clay binding agent, LSCB) obtained via mixed grinding of lime and rock were used as the binding agent. The correlation of lime and sandy loam in LSCB made 1: 2, specific surface – 770 m^2/kg. Raw mixes were prepared by mixing of the binding agent with the base rock. The lime content in raw mixes changed from 4 to 14 wt. %. The samples were molded from raw mix with 10% humidity under 20 MPa of pressing pressure, which is accepted within the traditional technology of lime brick.

The strength of the green brick on the basis of lime and sand (control) mix made 0.43 MPa. The use of sand clay rocks as siliceous component significantly increases the strength of the lime-sand brick, thus leading to the increase in strength with the increase in lime content (Figure 3). For raw mixes with lime content of 10 wt. % the influence of the pressing pressure on strength of the green brick was studied (Figure 4). It is found that the increase in pressing pressure from 10 MPa to 50 MPa leads to considerable increase in raw material strength, and as a result to the increase in operating properties of finished products.

Thus, the use of sand clay rocks instead of traditional quartz sand in the production of silicate materials improves molding of raw mixes, increases their strength by 4-11 times, which makes it possible to reduce product failures and facilitate the manufacture of high-hollow products.

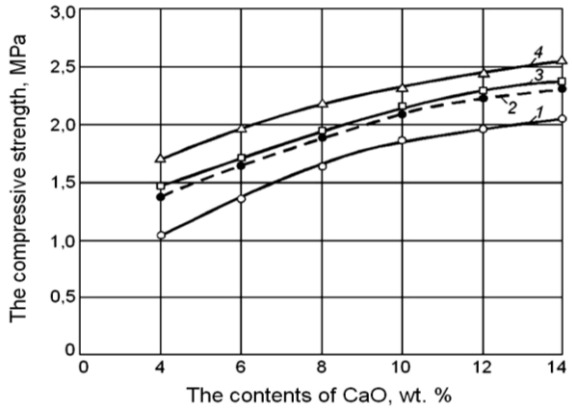


Figure 3. Influence of lime content on raw material strength. Rock: 1, 2 – sandy loam; 3 – loam 1; 4 – loam 2; binding agent: 1, 3, 4 – lime; 2 – LSCB.

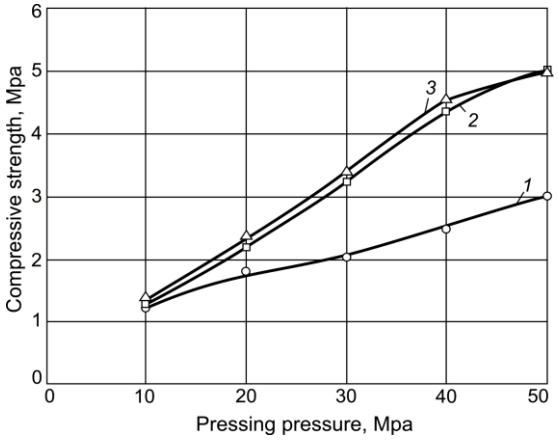


Figure 4. Influence of pressing pressure on raw material strength: pressing pressure, MPa: 1 – sandy loam; 2 – loam 1; 3 – loam 2.

In order to intensify the synthesis of new growths and to increase operational characteristics of composites the study focused on the influence of the composition of alumina-silicate binding agent

with nonconventional alumina-silicate raw materials on physical and mechanical properties of products. The compositions of raw mixes are given in table 2. The increase of sandy loam within a binding agent leads to the increase in strength from 18.9 to 20.2 MPa (Table 3).

Table 2. Compositions of raw mixes on the basis of alumina-silicate binding agent.

Composition	Lime content in raw mix, wt. %	Correlation of lime and sandy loam in a binding agent	Content of ground sandy loam in raw mix, wt. %	Content of initial sandy loam, wt. %	Specific surface of LSCB, m^2/kg
1	10	1 : 1	10	80	1040
2	10	1 : 1,5	15	75	980
3	10	1 : 2	20	70	770
4	10	1 : 2,5	25	65	650

Table 3. Physical and mechanical properties of silicate materials based on alumina-silicate binding agent.

Physical and mechanical properties	Composition			
	1	2	3	4
Pressing pressure 20 MPa				
Compression strength, MPa	18.90	19.60	20.02	20.20
Softening ratio	0.76	0.73	0.79	0.71
Average density, kg/m^3	1890	1900	1910	1855
Saturation factor, %	10.6	10.1	10.9	10.9
Pressing pressure 50 MPa				
Compression strength, MPa	31.3	32.8	31.5	30.5
Softening ratio	0.85	0.86	0.9	0.88
Average density, kg/m^3	2000	2150	2200	2100
Saturation factor, %	8.6	9	9.1	8.5

The increase in operational characteristics of obtained products is possible due to changes of the molding modes (Table 3). Therefore, in order to create high-density packing of material, and as a result to increase the strength properties of products it is advisable to apply higher pressure, which leads to the formation of a green brick, which, in turn, will improve the quality of high-hollow products.

4. Conclusion

The study proposes scientific and theoretical fundamentals of alumina-silicate binding agent design using technogenic raw materials in order to obtain non-autoclaved silicate materials. It is suggested to use alumina-silicate rocks of incomplete stage of clay synthesis as an active component of non-autoclaved silicate materials, which structure differs with regard to their thermodynamically-unstable compounds, which, in turn, may result in the production of efficient energy-saving high-hollow silicate materials of a new generation with up to 32 MPa compression strength, F15-25 frost resistance and 1100-1200 kg/m3 average density.

The use of optimized composition of alumina-silicate binder will ensure the formation of a more efficient composition of new growths, which contributes to the production of high-quality materials. The choice of the binding type will depend on the required characteristics of a product and on their final cost.

5. Acknowledgments

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6. References

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