CHEMICALLY- BONDED BRICK PRODUCTION BASED ON BURNT CLAY BY MEANS OF SEMIDRY PRESSING

Ivan Voroshilov[1, a)], Irina Endzhievskaya[1, b)], Nina Vasilovskaya[1, b)]

[1] *The Russian Federation, Krasnoyarsk, Svobodny Prospekt, 82*
FSAEI HVE Siberian Federal University
School of Engineering and Construction
a) Voroshilov I.S. e-mail: Nixon.06@mail.ru
b) Endzhievskaya I.G.e-mail: icaend@mail.ru

Abstract. We presented a study on the possibility of using the burned rocks of the Krasnoyarsk Territory for production chemically- bonded materials in the form of bricks, so widely used in multistory housing and private house building. The radiographic analysis of the composition of burnt rock was conducted and a modifier to adjust the composition uniformity was identified. The mixing moisture content was identified and optimal amount at 13-15% was determined. The method of semidry pressing has been chosen. The process of obtaining moldings has been theoretically proved, the advantages of chemically- bonded wall materials compared to ceramic brick were shown. The production of efficient artificial stone based on material burnt rocks, which is comparable with conventionally effective ceramic materials or effective with cell tile was proved, the density of the burnt clay - based cell tile makes up 1630-1785 kg \ m^3, with compressive strength of 13,6-20,0 MPa depending on the compression ratio and cement consumption, frost resistance index is F50, and the thermal conductivity in the masonry is λ = 0,459-0,546 W \ m * ^{0}C. The clear geometric dimensions of pressed products allow the use of the chemically- bonded brick based on burnt clay as a facing brick.

Introduction

The use of burnt rocks increased sharply due to the need for the full increase in the production of wall constructional materials in the Krasnoyarsk Territory. Construction companies engaged in general contracting and contracting services of various directions and complexity intend to carry out the full construction cycle in practice: from design, production of construction materials, the actual construction (construction of facilities) prior to the sale and operation of facilities. With powerful resources - management of the enterprise for the production of ready-mixed concrete, precast concrete, building contractors don't want to depend on manufacturers of wall materials, intending to carry on the entire volume of production of construction materials. Therefore, the production of chemically- bonded bricks based on burnt rocks is a way out of this situation and the development of formulations and technology for effective chemically bonded wall building materials based on burnt rocks that meet the requirements of modern construction that is achieving an urgent task.

Methodology

Compliance with laws revealed the formation of the basic technical and operational characteristics of the developed modified material mounted on the stage of laboratory research and research samples of products manufactured in industrial conditions.

Experimental-industrial tests confirmed the possibility of obtaining molded stone material on the basis of burnt rocks with high strength properties. The possibility and feasibility of the production of the artificial wall building stone by means of semidry pressing based on burnt clay have been proved.

The necessity of research concerning the effectiveness of methods of molding and chemical modification of chemically- bonded wall material based on burnt clay to solve the problem of using non-homogeneous composition and structure burned rocks has been identified.

Material and equipment

The types and characteristics of used materials have been presented, the methods of experimental research have been described. Studies were conducted on the basis of burnt rocks (burnt clay) extracted from Irsha- Borodino open-cut and Uyarskoe field. Cement produced by "Krasnoyarsk Cement" was used as binder.

The following studies were conducted: X-ray phase diffraction and chemical analysis (X-ray diffractometer D8-ADVANCE (Bruker) and X-ray fluorescence spectrometer for the analysis of the elemental composition of ARL OPTIM, X, ("TermoTehno", Switzerland) different areas of burnt clay of Uyarskoe field were investigated in order to use wall materials in production. Investigations of raw materials (burnt rocks and extracted products based on burnt rocks) were carried out in accordance with the regulations using standard equipment.

Research

Conducted research suggests that burnt rocks in physical form, structure and physical-mechanical properties are close to the burnt ceramic crocks, as they were formed in the process of burning the natural clay, sand and clay deposits. There are hardly ever melted areas in burnt clay. Colorful, rich and durable painting of burnt rocks makes it possible to manufacture the facing products of light pink, yellow, purple, orange and red tones on their basis.

As a result of investigations dealing with burnt rocks in Siberia several fields have been identified, the most important are the following: Irsha-Borodino, Chernogorskoe, Nazarovskoye, Uyarskoe fields. However, burnt clay of these deposits has no industrial use so far.

The possibility to use burnt rocks for the production of wall materials set the task of studying their properties. X-ray phase analysis various areas of burnt rocks, differing in color was carried. It was assumed that darker color that is closer to brown areas of burned rocks could be referred to the well-fired siltstones. Burnt rocks of grain color could be referred to light-fired siltstones and sandstones.

XRD pattern of burnt rock, in particular, its dark brown part is shown in Fig. 1, indicating quartz SiO_2, (d=0.333; 0.245; 0.227; 0.212; 0.197; 0,181 nm, , and others), cordierite ((Mg, Fe)$_2$Al$_3$ [AlSi$_5$O$_{18}$] - (d =0.491;0.464; 0.337; 0.313;0.265 ;0.245 NMI nm, , and others). In addition, the composition of burnt clay contains diffraction peaks that are peculiar to α-trydimite (d = 0.432; 0.382; 0,297 nm, and others) and hematite Fe_2O_3 (d = 0.367; 0.269; 0.219; 0.183; 0.169 NMI, and others). Cordierite is formed by burning out of rocks, α-trydimite is a high-temperature modification of quartz. Samples seem to be more homogeneous, hard burned and more crystallized.

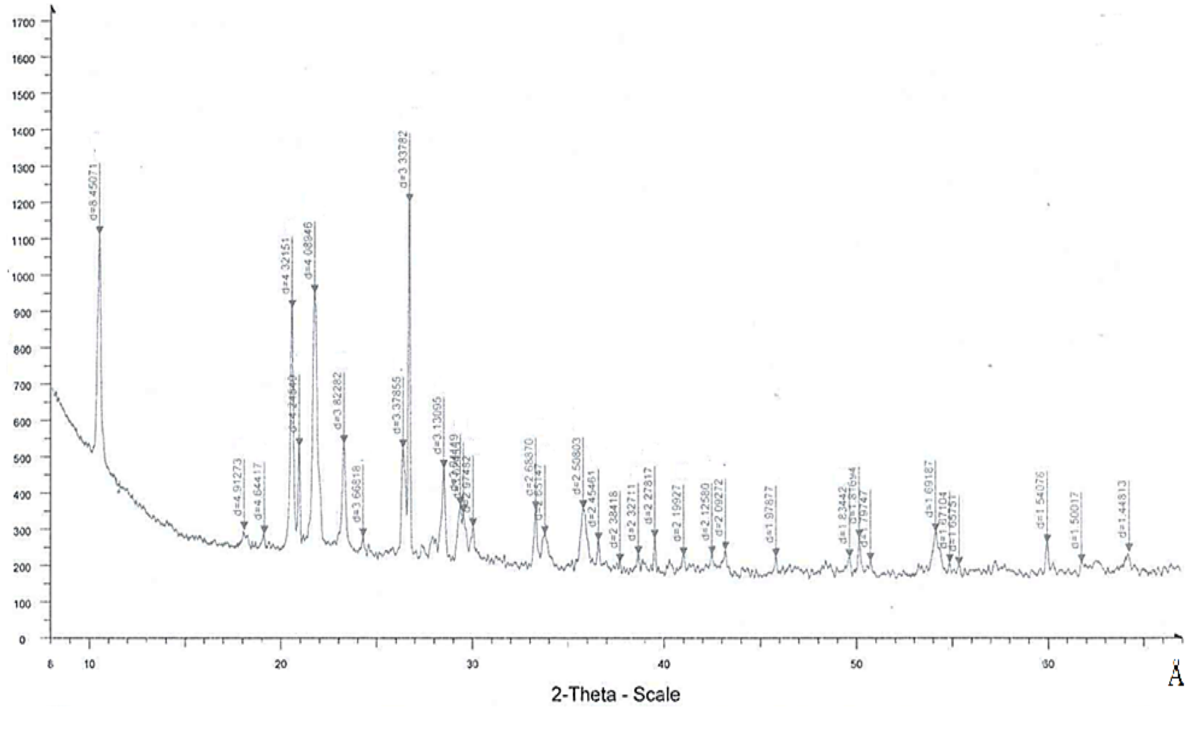

Figure 1. XRD pattern of dark brown part of burnt rocks

The light part of the rock is characterized by the presence of feldspathic rocks (aluminum silicates Na, K, Ca) of variable composition (Figure 2) with diffraction peaks (d = 0,405; 0, 391; 0,377; 0,363nm, and others).

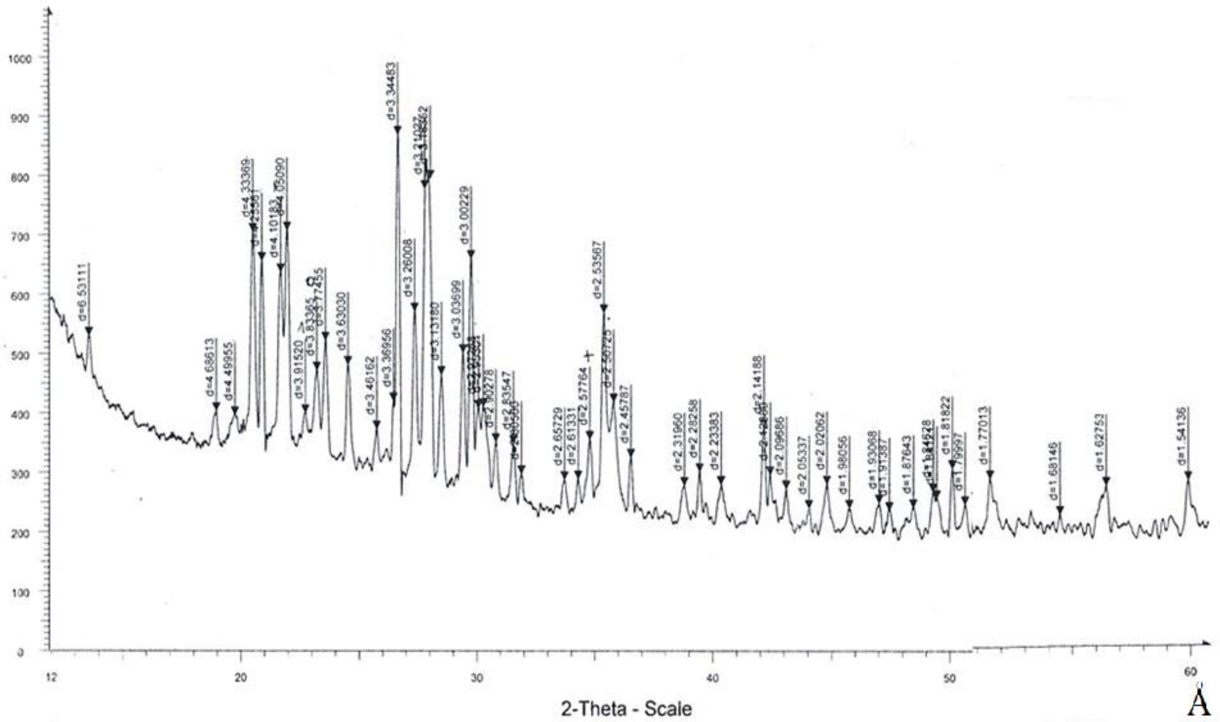

Figure 2. XRD pattern of light- red part of burnt rocks

Table 1 shows the data of chemical composition of the test samples of burnt rocks of Uyarskoe field in Krasnoyarsk Territory in comparison with burnt clay of other fields, such as Kuznetsk coal field, Podmoskovniy field, Kildyamsk field in Yakutia.

Table 1. Chemical composition of burnt rocks of various fields

№ пп	The name of burnt rocks field	The content of oxides, mass %								
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	loss on ignition
1	Uyarskoe field of Krasnoyarsk Territory (Tula-2)	63,95	19,71	8,0	2,61	1,58	0,05	0,30	2,81	1,02
2	Irsha-Borodino field	52,11-68,3	13,5-19,3	3,2-10,1	2,4-8,42	1-2				1,3-2,1
3	Kildyamsk field Republic of Sakha (Yakutia).	63,23-65,74	20,19-19,42	7,58-7,97	1,45-9,96	1,37-1,64				1,25-1,16
4	Burnt rocks of Kuznetsk coal field (the Kemerovo region)	39,1-77	14,7-26	6,9-11,4	0,6-7,6	0,8-2,5				0,10-1,24
5	Podmoskovniy field	55,1-61,3	28,3-35,1	- -	0,84-1,2	0,28-1,98				2,32-7,80

There are no special differences according to the content of Fe_2O_3 oxides in the burnt rocks there. At the same time the content of Al_2O_3 in rocks of Uyarskoe field is significantly lower compared with burnt rocks of near Moscow and Kemerovo region. The latter gives reason to believe that resources development of Krasnoyarsk Territory is possible at lower temperatures.

Real average density of burnt clay, porosity and strength of rock and water absorption are shown in Table. 2.

Table 2. Properties of burnt rocks

The average density ρ0, kg / m^3	The true density ρ, g / cm^3	Porosity, %	The strength of the rock, MPa	Water absorption, % by weight
1630-2080	2,62	20-37	21,7-34,4	16-22

The strength of rock stone determined by breakability when compression (crushing) in the cylinder in accordance with GOST 8269.0-97 corresponds to the type of 200-300 when testing rock stone of burnt rocks in a dry condition with the weight loss from 28,0 to 31.5%.

Bulk density of burnt clay dried to constant weight condition fraction 5-15 - 930 kg / m^3 based on the burnt sand rock - 1050 kg / m^3. Therefore, the strength was also defined as porous aggregates, according to GOST 22263, crushing in a cylinder and was 13.2 - 21.1 kg / cm^2, and the type according to strength of rock stone from porous rocks corresponds to from P 150 to P 250.

According to the requirements of GOST, the type of crushed rock stone with strength P 150 should correspond to the bulk density of 800 kg / m^3 P 250 - 1000 kg / m3. Burnt rocks of Uyarskoe field are characterized by density of 930 kg / m^3 (fraction 5-15) with the strength of P 150 P 250.

Thus, these physical-mechanical tests of burnt rocks confirm the data of petrographic observations, as well as chemical analysis of the heterogeneity of properties of the burnt rock. Physical and mechanical properties of burnt rocks are dependent on the degree of burning. Less burnt rocks have higher water absorption, lower density and compressive strength. These physical and mechanical tests, allow us to consider that it is possible to use burnt rocks in the production of chemically- bonded bricks.

For the production of wall materials based on burnt clay (Figure 3) we used the method of semidry pressing, which is widespread in the manufacture of ceramic products - bricks, tiles, refractory ceramic and silicate bricks. The method of semidry pressing allows to get chemically-bonded brick based on burnt clay with a glazed surface, clear geometric dimensions with minimal deviations of the planes. The task of overcoming the irregularities in the composition and structure of burnt clay was solved with the use of additives, on the one hand, by means of the modified additive for semidry pressing produced by "MC Bauchemi" Ltd, on the other hand, by means of technology, selection of wall molding products.

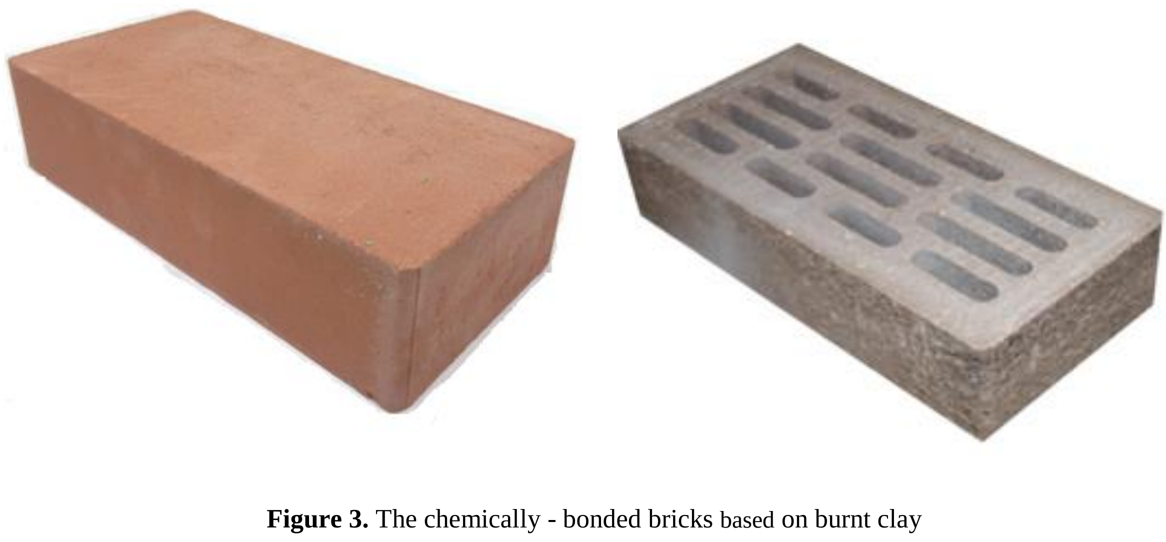

Figure 3. The chemically - bonded bricks based on burnt clay

When semidry pressing in various technologies humidity of pressed mass and pressing pressure applied to it is different. For example, in the production of conventional ceramic brick the moisture is 8 ... 12% at a pressure of 20 ... 30 MPa, in case with various refractories the molding humidity corresponds to 4 ... 11%, pressure of 20 ... 40 MPa; silica brick is formed with a moisture content 7 ... 9%, pressure corresponds to 25 MPa.

Since the burnt rock is porous and characterized by low density and strength, this technology will allow us to harden materials on their basis. Products made from more dense rocks according to this technology are too heavy, their density is 2000 kg / m3 or more, respectively, with high thermal conductivity. Therefore, semidry pressing technology for wall materials on the basis of burnt rocks was adopted as the main, their relatively high porosity results in a chemically- bonded bricks with density corresponding to the density of the ceramic brick, burnt with using burning additives.

The furnace charge for the production of chemically- bonded bricks, which is fed to the press, seems to be mineral particles of burnt rock having substantial porosity, and as a result there is no film of moisture on their surfaces. Moreover they are characterized by cement binding in the form of a mixture of the colloidal particles with a small amount of free and bound moisture. Molding was carried out by means of semidry pressing at pressure of 20,0-32,0 MPa in order to meet the compacting ratio within 1,59-1,64.

Pressing process may be divided into several steps that are different in the behavior of mass structural elements.

The beginning of pressing the furnace charge for the production of chemically- bonded bricks based on burnt clay is accompanied with compacting of loosely packed particles due to their displacement relative to each other in the direction of the pressing forcer with filling large pores, and their bonding. In this step, deformation of individual particles of burnt clay hardly happens. This results in a partial removal of air from the system. When you reach a certain compacting pressure the largest particles of burnt clay occupy a relatively stable position, and their further compacting is determined by deformability processes.

The second stage of compacting is characterized by a plastic irreversible deformation of burnt clay particles with its partial destruction, mostly concerning surface - cutting rough edges and offsets. This increases the contact surface between the particles. Simultaneously, compacting each grain of the furnace charge is accompanied by squeezing water from the deep layers of it to the contact surface. Both these factors cause the change of phase composition, structure and properties of the material of the diffusion layer, increasing bonding between particles. With increasing pressure, the growth of elastic deformation continues, not only the absolute value increases but their share in the total compression system rises as well.

The behavior of compressed burnt clay grains for the formation of structure of chemically-bonded bricks is of great importance as well the phenomena occurring in the liquid and gaseous components of the system. Due to the furnace charge compression and decrease of total volume of pores the quantity of water in this volume increases. When subjected to the influence of forces the water of a diffusion layer is pressed into the pore space of burnt clay. Since the primary water content exceeds the optimal consumption in the furnace charge (13-15 wt%), its volume can be approached or equal to the total pore volume, i.e. the system reaches a critical density at the critical pressure. Further compression of the system is reduced to the reversible elastic deformation.

The air contained in the furnace charge is displaced outwards through the gaps of the form, with increasing pressure air cells become narrower, they are filled with squeezed water, while partially closing, and therefore displacement of air slows down, the pressure of remained "extruded" air in the system increases to the major degree according to larger number of fine-grained particles and higher compression rate.

The behavior of the liquid and gaseous phases when pressing chemically- bonded brick based on burnt clay explains to some extent the pattern of declining physical and mechanical properties with increasing compacting pressure more than 28 MPa (Table 3).

Table 3. Dependence of the physical and mechanical characteristics of the chemically- bonded brick based on burnt clay on compacting pressure.

Physical and mechanical properties of chemically- bonded bricks.	Compacting pressure, MPa			
	20	24	28	32
Compressive strength at the age of 7 days MPa	16,7	17,5	18,9	17,9
The compressive strength at age 28 days MPa	18,2	19,0	20,5	18,6
Average dry density, kg / m^3	1690	1720	1765	1783

In addition to liquid and gaseous phase, the quality of the compacted products also affects the method of applying pressure. The value of the compacting pressure at the surface of the forcer (the surface of the load) decreases as the distance from its compacting layers of the furnace charge due to the influence of external forces on the walls of the mold friction. Accordingly, there may be a different density of as-formed product according to thickness pressing, decreasing the product layers that are the furthest from the forcer surface.

Therefore in order to get chemically-bonded bricks based on burnt clay press A300-C2 was used. A characteristic feature of the press is the opposite direction of the two hydraulic cylinders. Bilateral compaction reduces the degree of non-uniformity of product density, improving the quality of the products. In addition, the pressure drops and density across the thickness of the product is further reduced by means of using additives for semidry pressing, which increase formability, bonding and compressibility of furnace charge, facilitate wetting of the components.

Water contained together with colloidal particles cements the particles of burnt clay in the press-work, and with increasing the contact surface the effect of such a cementation increases. Compliance with moderate effective moisture content plays a special role at this stage.

The last stage of compacting is accompanied with brittle fracture of particles, wherein the press-work receives the t highest degree of compacting and bonding due to further strong development of contact surface.

Burnt clay (being inert rock) subjected by the mutual friction, partially crushing of fine-grained particles during compression, are activated in the diffusion layer, there is a breakdown of the oxide film on the surface of the particles, with the formation of free oxides - open juvenile surfaces, in connection with which the particles stick together, they are pressed into the interlinked surfaces. In addition to the cohesion around the particles of burnt clay thin patterned layers from cement paste are formed that accelerates hydration processes and increases the final strength of the products. Defects in the structure are additionally filled with formed crystal hydrates with the crystallization of small stable crystals in the pores and fissures of the material.

Conclusion

The principle possibility of producing an effective artificial stone material based on burnt rocks with heterogeneous composition have been theoretically substantiated and experimentally confirmed by means of semidry pressing technology using modifying additives.

The compositions on the wall material based on burnt clay using modifying additives have been developed, mechanisms for the advancement of structural parameters have been established. The advantage of chemically-bonded, molded wall materials (in the form of bricks or stones) based on burnt rock is that they have a sufficiently high strength equal to or exceeding ceramic bricks at the same average density. The density of the wall material based on burnt clay corresponds to 1630-1785kg / m^3, the compressive strength of 13,6-20,0 MPa depending on the flow rate and sealing cement F50 frost resistance, the thermal conductivity in the masonry λ = 0,459-0,546 W / m $\cdot$ ^{0}C. According to average density they are comparable to conventionally-effective ceramic materials, or they are proved to be effective in case of presence of effective technological voids. At the same time, they have a good surface, clear geometric dimensions, color from red to brown, that allows the use of wall materials based on burnt clay as a facing brick.

References:

1. Narottam P. Bansal and Jacques Lamon, *Ceramic Matrix Composites: Materials, Modeling and Technology (The American Ceramic Society, Ney Jersey, 2015),* pp. 175-182.
2. H. Okamura and M. Ouchi, **Journal of Advanced Concrete Technology** Vol. 1, No 1, P. 5–15. (2003).
3. Gilbert C.Robinson, *Ceramics and Glasses (*ASM International, Clemson, 1992), pp. 943-950.
4. Michael A. Caldarone, *High-Strength Concrete a practical guide* (Taylor & Francis , Ney York, 2009), pp.30-33, 47-55.
5. Robert J. Pugh, Lennart Bergstrom**,** *Surface and Colloid Chemistry in Advanced Ceramics Processing (Marcel Dekker, Inc.,*New York, 1994), pp. 15-19.
6. Knigina G.I., *Stroitel'nie materialy iz gorelih porod* (Izdatel'stvo literatyri po stroitel'stvy, Moskva, 1986)- s. 15-26.
7. Gorshkov V.S., Timashev V.V., Savel'ev V.G., *Metody fiziko-himicheskogo analiza vyazhyshih veshestv* (Vishazhaya shkola, Moskva, 1981) 335 s.
8. Boldyrev A.S., Zolotov P.P, Lysov A.N., *Stroitel'nie materialy: Spravochnik* (Stroyizdat, Moskva, 1981), 345-346 s .
9. Cherepov V.D., Kononov O.V., **Tehnicheskie nayki 9,** s. 1200-1204, (2014).