Silica clay (opoka) as a promising raw material for unfired wall products by compression molding

Svetlana Kurilova*, *Aleksey* Naumov, and *Berhane* Gebru

Don State Technical University (DSTU), 344000 Rostov-on-Don, Russia

Abstract. The article is devoted to the actual problem of producing unburnt wall products of compression molding with improved and high efficiency in terms of thermal and engineering properties. The article notes the relevance, attractiveness, and wide use of unburnt pressed products in modern civil engineering. The raw material composition and production technology of unburnt wall products of compression molding are described. The traditionally used aggregates for unburnt wall products of compression molding are reviewed and their properties are analyzed. High average density and high thermal conductivity are noted in these products. The objective is to improve the thermal characteristics of these products while ensuring their strength properties. For this purpose, it is proposed to introduce a porous component of siliceous rock called opoka (silica clay) into the raw material composition of products as a mineral filler. Opoka collected from three different deposits was reviewed, its characteristics given, and the raw material analyzed. It is noted that the porosity and average density of opoka depend on its deposit. The effect of porosity and average density of opoka on the average density, compressive strength, and water absorption of unburnt wall products of compression molding based on opoka with different porosities from different deposits is described. The effect of the properties of opoka on the properties of unburnt wall products of compression molding is explained. It is confirmed that the use of opoka in the production of unburnt wall products reduces the average density of the products and improves their thermal and engineering properties. The appropriateness of manufacturing large-sized hollow wall blocks based on opoka is substantiated.

1 Introduction

The construction of new houses and buildings, street paving, and giving a modern architectural style to urban buildings indicate the development of urban planning [1, 2, 3, 4]. At present, modern building materials are used in construction, among which we can distinguish non-fired pressed products based on cement and mineral aggregate [5, 6, 7 ,8]. According to their purpose, they are subdivided into wall (ordinary facing bricks, facing stones, and facing tiles), road (paving tiles, paving stones, and curbs), and products of small

* Corresponding author: svet.curilova@yandex.ru

architectural forms. Intensive development in civil engineering has led to increased demand for wall and facing products. Unfired pressed ordinary bricks are made based on local mineral raw materials (the screenings of crushed rocks: limestone and sandstone), Portland cement, and water by the semi-dry pressing method at a pressing pressure of 20–30 MPa. The mineral aggregate used is dense. The cement content in the mixtures is recommended to be 10–15%, and the water content of the mixtures is approximately 6–8% of the mass of dry materials. The lower water content in the mixtures is explained by using dense aggregates. The brick obtained by this method has a strength grade of M200–M250 and a frost resistance grade of F25. The unfired pressed facing brick is also made by means of semi-dry pressing based on cement, water, pigments, and mineral aggregate and has a strength mark of M250–M300, a weight of 2–4,3 kg, water absorption by weight up to 8%, and a frost resistance of F75. Exterior products such as brick, stone, and tile are very familiar in building construction. Unfired pressed wall products look like natural stones in appearance and surface texture. These products perfectly combine with ceramic bricks and wooden wall surfaces, harmonize with tiled roof slopes, mosaics, and stained-glass windows, and effectively contrast with smooth plastered surfaces and cladding. There are more than 800 colors and shades of colored face bricks to satisfy the wide demand of consumers. However, the unfired pressed bricks produced have a high mass and low water absorption by mass. This indicates that the material has a relatively high average density and high thermal conductivity. Therefore, an urgent task in the field of obtaining unfired pressed wall products is to reduce their average density and thermal conductivity while maintaining strength and frost resistance. Our research shows that the solution to this problem can be achieved by using a porous aggregate called opoka (silica clay) in non-fired pressed wall products. Opoka is a light, thin, porous rock, consisting mainly of the smallest (less than 0,005 mm) particles of opal-cristobalite. The average density of opokas is 1100–1600 kg/m^3. The porosity of opoka reaches 55% (usually 30–40%).

The strength of the strong silica-like varieties is up to 150 MPa; "normal" is from 5 to 20 MPa; and weathered is from 3 to 7 MPa. The color of opoka varies from light yellow to dark gray. Opoka is porous and has the necessary strength, frost resistance, and chemical activity, which makes it attractive for use in the manufacture of pressed wall products [9, 10]. For non-fired-pressed products, it is advisable to use siliceous opoka. They are mineral fossils and were formed during intermediate eras from carbonate accumulation into siliceous accumulation. The carbonate material is continuously deposited in the basins, and the process of silicification is ongoing, accompanied by the formation of highly siliceous zeolites. Such rocks have a natural charge with the necessary stoichiometry (1-2) $CaO:SiO_2$. The total silica content in opoka is 68–78%, and in sandy and siliceous varieties, its amount may increase up to 85–90%. In clayey and calcareous varieties, the amount of silica decreases. Silica is present in opoka in three main forms: as quartz, which is a terrigenous admixture in opoka; as silica in clay minerals; and as opal silica, which is the main part of the rocks. Like other siliceous rocks (diatomite and tripoli), opoka is a multi-component system. These rocks, along with amorphous silica, contain clay minerals, impurities of sandy siltstones, and carbonate materials, the particles of which are usually less than 0.010 mm in size. The variety of composition, the presence of a large proportion of opal in opokas, and their physical properties make the rocks attractive in the production of non-fired pressed wall products [9, 10]. More than 200 opoka deposits have been discovered in the Rostov Region. The right-bank part of the Rostov region has a large raw material base of opal-cristobalite raw materials. The reserves explored according to industrial categories (Malchevskoe, Peskov-Lopatinskoe, Avilo-Fedorovskoe, Uspenskoe, and other deposits) are about 3350 thousand cubic meters. Forecast reserves are dozens of times greater. Opoka usually lie near the surface, on elevated areas, as terrain-forming sediments. Opoka deposits are distinguished by a high thickness (up to tens of meters) and pronounced composition, which creates good mining preconditions for the development of deposits. The considerable raw material base of opoka creates a basis for its wide use in the manufacture of building materials and products [9]. One of these types of products are non-fired wall products made by compression molding—bricks and stone.

2 Research methodology

In the experimental studies, screenings from the crushing or sawing of rocks (opoka) were used with their subsequent sieving. As a mineral aggregate, the silica clay (opoka) contained sandy fractions with grain sizes less than 2.5 mm [11]. Opoka and cement were a dry mixture. In the dry mixture, cement consumption was relatively low—15%, and the rest—85% accounted for opoka. The water consumption in the compositions was determined over 100% of the dry mixture and set experimentally for each type of opoka, considering its porosity, to ensure the highest density and strength of the cured material. Molding mixtures consisting of cement, opoka, and water were semi-dry mixtures—press powders—that were easily poured into a metal mold matrix and compacted at a pressure of 30 MPa with the application of pressing force from below and above the mixture. This type of product pressing is called compression molding [10]. Freshly molded products had sufficient demolding strength (not less than 1 Mpa) required for transportation and were therefore immediately removed from the press matrix, placed on the pallet, and sent for curing. The products were cured under the conditions of heat and humidity treatment at the temperature of isothermal curing at 85°C under the scheme of (2+6+2) hrs. Before testing the cylindrical samples with a diameter and height of 5 cm, their mass and dimensions were determined. The compression test of the specimens was carried out at the age of 28 days on a hydraulic press with a capacity of 10 tons. The results of the tests were recorded in the laboratory journal and processed according to standard procedures.

3 Results of the study

For the study, we chose opoka from the Nagolnovskoe (carbonate opoka), Avilo-Fedorovskoe, and Taskalinskoe deposits with different porosities and correspondingly different average densities. The Nagolnovskoe deposit had a porosity of 34% (Fig. 1) and an average density of 1650 kg/m^3 (Fig. 2); the Avilo-Fedorovskoe deposit had a porosity of 46% (Fig. 1) and an average density of 1300 kg/m^3 (Fig. 2); and the porosity of the Taskalinskoe deposit had a porosity of 52% (Fig. 1) and an average density of 1120 kg/m^3 (Fig. 2).

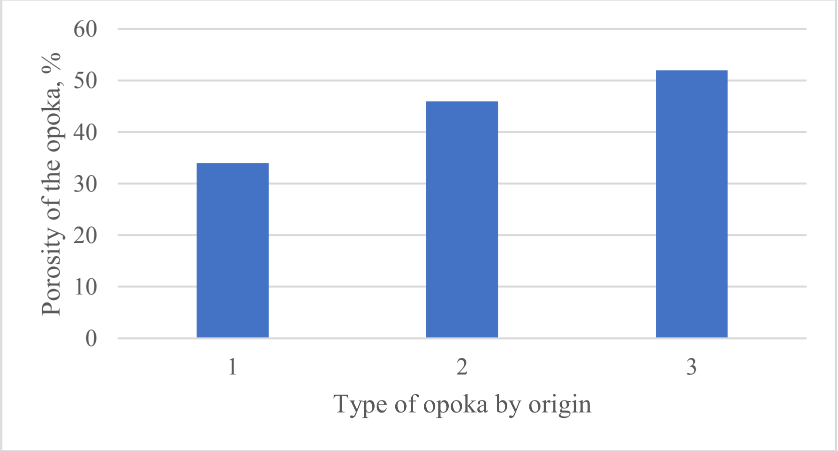

Fig. 1. Dependence of porosity of opoka on its origin: 1 - Opoka of Nagolnovskoye deposit; 2 - Opoka of Avilo-Fedorovskoye deposit; 3 - Opoka of Taskalinskoye deposit.

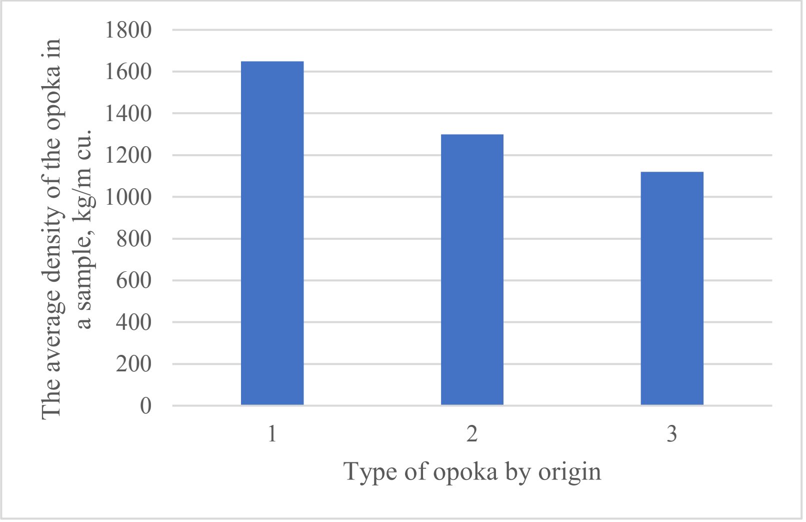

Fig. 2. Relationship of the average density of the opoka in a sample to its origin: 1 – Opoka of Nagolnovskoye deposit; 2 – Opoka of Avilo-Fedorovskoye deposit; 3 – Opoka of Taskalinskoye deposit.

Based on these silica clay (opoka), cylindrical samples were produced by compression molding at a specific pressing pressure of 30 MPa. In the composition of the pressed material, the consumption of Portland cement of class 32.5 was 15% by mass, the consumption of opoka was 85% by mass, and the water consumption was 12% by mass with opoka of the Nagolnovskoye deposit, 19% with opoka of the Avilo-Fedorovskoye deposit, and 31% with opoka of the Taskalinskoye deposit, which was taken above 100% of the dry mix by mass. The water consumption rate depended on the porosity of the opoka and was set with the purpose of ensuring the highest average density and compressive strength of the cured material, considering the lowest values of water absorption by mass. The high-water consumption in opoka-based press powders is due to the high microporosity of the opoka and its low average density. The effective pore radius of the opoka is usually less than 10–9 m. After the heat and humidity treatment was applied, the samples were tested and their physical and mechanical properties determined (Table 1). The average density of the pressed material in a dry condition in samples based on the opoka from the Nagolnovskoye deposit was 1680 kg/m^3, the opoka from the Avilo-Fedorovskoye deposit was 1360 kg/m^3, and the opoka from the Taskalinskoye deposit was 1210 kg/m^3. The compressive strength in a dry condition in samples based on the opoka from the Nagolnovskoye deposit is 45 MPa, the opoka from the Avilo-Fedorovskoye deposit is 30 MPa, and the opoka from the Taskalinskoye deposit is 34 MPa. Water absorption by mass was 25% in samples based on Nagolnovskoye deposit opoka, 29% based on Avilo-Fedorovskoe deposit opoka, and 46% based on Taskalinskoye deposit opoka.

Table 1. Physical and mechanical properties of samples.

Silica clay (opoka) deposit	**Average density of the silica clay in a sample, kg/m³**	**Porosity of the silica clay, %**	**Physical and mechanical properties of samples**		
			Average density in dry condition, kg/m³	Compressive strength in dry condition, MPa	Water absorption By mass, %
1	2	3	4	5	6
Nagolnovskoye	1650	34	1680	45	25
Avilo-Fedorovskoye	1300	46	1360	30	29
Tuskalinskoye	1120	52	1210	34	46

4 Discussion of the results

The results of the experiment (Table 1) show that with increasing porosity of the silica clay (opoka) and reducing its average density in the sample, the average density of the pressed material decreases and its water absorption by mass increases while ensuring sufficient compressive strength for pressed wall products. The compressive strength of the pressed material in the dry state in the samples based on the opoka of all three deposits was not less than 30 MPa, which is sufficient for wall products [12]. The high strength of compression molded products based on silica clays (opoka) is explained by the close contact of particles of pressed material due to bilateral application of pressing force at high pressure [6] and chemical reactions between calcium hydroxide $Ca(OH)_2$, (a cement hydration product), and amorphous silica ($SiO_{2\ amorphous}$), a part of silica clay (opoka), which forms low-base calcium hydrosilicates. The higher average density of the pressed material is observed in samples with opoka from the Nagolnovskoye deposit (1680 kg/m³), as this opoka has the highest average density in a sample and the lowest porosity. The lowest density of the pressed material is observed in samples with opoka from the Taskalinskoye deposit (1210 kg/m³), as this opoka has the lowest average density in a piece and the highest porosity. Lower water absorption by mass of the pressed material is observed in samples with opoka from Nagolnovskoye deposit (25%) as this opoka has the lowest porosity, and the highest water absorption is observed in samples with opoka from Taskalinskoye deposit (46% as this opoka has the highest porosity). It is necessary to note the significant water absorption value by mass in pressed products based on opoka (25–46%). Such high-water absorption determines the use of opoka for ordinary wall products, which should be covered with more water-resistant materials. For ordinary products, the determining properties are average density and ultimate compressive strength, and water absorption by mass can be disregarded. The decrease in the average density of ordinary wall bricks with an increase in the porosity of the opoka consequently leads to a decrease in the thermal conductivity of these products and increases their effectiveness in terms of thermal and engineering aspects. The high strength of the pressed material based on opoka makes it possible to produce hollow products. Making hollow products is another opportunity to reduce their average density and thermal conductivity. The combination of porosity of opoka and hollowness of extruded products allows to significantly improve the thermo-technical characteristics of these products by moving from ineffective products based on dense aggregates to high-efficiency products based on porous aggregate, opoka [12]. If we make wall products with 50% hollowness based on the considered opoka, the average density of the Nagolnovskoye opoka will be 840 kg/m³, of the Avilo-Fedorovskoye opoka, 680 kg/m^3, and of the Taskalinskoye opoka, 605 kg/m^3. By average density, products based on opoka from the Nagolnovskoye deposit have increased efficiency in thermal and engineering characteristics, and products based on opoka from the Avilo-Fedorovskoye and Taskalinskoye deposits have a high efficiency group [12]. The most promising type of such product from the thermal and engineering point of view, physical and mechanical properties, and convenience of use could be a hollow wall block with dimensions of 250x250x140 mm with circular cavities (Fig. 3).

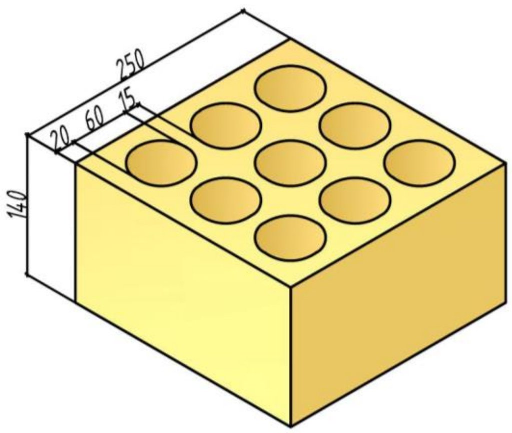

Fig. 3. Wall hollow block of compression molding.

5 Conclusion

Experiments show that the use of silica clay (opoka) as a porous mineral aggregate in non-fired wall products of compression molding can achieve the following results:

- provides a compressive strength of at least 30 MPa, which is enough for ordinary and face wall bricks;
- with a decrease in the average density of the opoka in a sample, the average density of the pressed material decreases, and, therefore, its porosity and water absorption by mass increase, and the group of products improves in terms of thermal and engineering characteristics;
- the use of opoka with an average density in a sample from 1100 to 1600 kg/m3 and making the hollowness of wall blocks about 50% leads to the fact that the blocks based on the opoka of Nagolnovskoye deposits will have increased efficiency in terms of thermal performance, and the blocks based on the opoka from Avilo-Fedorovskoye and Taskalinskoye deposits will have high efficiency in terms of thermal performance;
- the most promising type of product from a technological point of view, in terms of physical and technical properties and features of application, can be a hollow block with dimensions of 250×250×140 mm with circular cavities;
- products based on opoka have a light-yellow color and the possibility of producing the pressed material in a wide range of colors, which makes them attractive and highly desirable in modern architectural styles;
- high water absorption by mass determines the use of products for interior walls of buildings, and if products are used for exterior walls, it is necessary to cover (plaster) them from the outside with more water-resistant materials;

- the actual focus of further research should be to improve the water resistance of products;
- the special technology used to produce extruded wall products ensures their lower production costs compared to clay bricks.

References

1. M. Safiuddin, M. Z. Jumaat, M. A. Salam, M. S. Islam, R. Hashim, Inter. J. Phy. Scie. **10(5)**, 1952 (2010)
2. F. Pacheco-Torgal, P. B. Lourenço, J. A. Labrincha, S. Kumar, P. Chindaprasirt, *Eco-efficcient Masonry Bricks and blocks*. *Design, properties and durability*/ F. (Woodhead Publishing, 2015)
3. D. M. de Souza, M. Lafontaine, F. Charron-Doucet, B. Chappert, L. Lima, J. Clean. Prod. **137**, 70 (2016)
4. M. Pedroso, J. de Brito, J. D. Silvestre, Const. & Build. Mater. **140**, 221 (2017)
5. S. N. Kurilova, Don Eng. Bul. (Inzh. Ves. Dona) **2,** (2017)
6. S. N. Kurilova, Sci. Rev. (Nauch. oboz.) **22**, 153 (2015)
7. E. O. Lotoshnikova, V. N. Telegina, L. M. Usepyan, I. M. Usepyan, Don Eng. Bul. (Inzh. Ves. Dona) **1**, (2018)
8. E. O. Lotoshnikova, L. M. Usepyan, V. N. Telegina, I. M. Usepyan, Don Eng. Bul. (Inzh. Ves. Dona) **2**, (2018)
9. B. V. Talpa, A.V. Kotlyar, Buil. Mat. **4**, 31 (2015)
10. V. D. Kotlyar, Don Eng. Bul. (Inzh. Ves. Dona) **3**, (2012)
11. G. V. Bogdanova, I. V. Kapitonov, V. D. Cherepov, Bul. Scien. Conf. (Vest. Nauch. konf.) **2(42)**, 118 (2019)
12. GOST 530-2012 Bricks and ceramic stone. General technical conditions, https://docs.cntd.ru/document/1200100260