



Special features of obtaining a high-strength ceramic body based on modified argillites

Orlova M.E. * ¹ 

¹ Don State Technical University, Russia

Abstract: After studying construction market trends over the past year, a rapid decline in ceramic materials production was revealed. According to Rosstat, construction materials output fell by 8.6% in September 2025 compared to the same month last year. Regarding the ceramic materials market, a decline was observed in the ceramic brick, stone, and tile production segment. Production of construction bricks decreased by 3.8%, ceramic stone by 4.8%, and ceramic facade tiles by 3.1%. Furthermore, clinker roofing tiles, large-format ceramic tiles, and siding are unavailable on the market, as imports of these products are limited and domestic production is nonexistent. Many ceramic material manufacturers are prepared to be modernized to support import substitution, thereby reducing the shortage in the construction industry. The primary challenge currently is to find raw materials suitable for the production of high-strength ceramic products. Argillites, which are widely distributed throughout the Russian Federation, could serve as such raw material. The main deposits of this raw material are located in the Southern and North Caucasian Federal Districts.

Keywords: high-strength ceramics, argillites, modified argillites, mineralizer, water absorption, production technology, flat extrusion

Please cite this article as: Orlova M.E. Special features of obtaining a high-strength ceramic body based on modified argillites. Construction Materials and Products. 2026. 9 (3). 2. DOI: 10.58224/2618-7183-2026-9-3-2

1. INTRODUCTION

According to GOST 9169-2021 "Clay raw materials for the ceramic industry. Classifications" for the production of ceramic products, medium-sintering clays of low- and medium-temperature sintering, free of natural impurities, are recommended for the production of ceramic products. Such clays became scarce, though they were the main raw materials for the production of ceramic products. Therefore, an urgent task is to find a new affordable type of raw material for the production of ceramic high-strength products using the flat extrusion method. Products such as facade and floor tiles, roof tiles, siding, window sills, steps, etc. are suitable for this production technology.

*Corresponding author E-mail: marina.nekrasova.96@list.ru

According to previous studies, it was revealed that argillites can become an alternative raw material for ceramic production. One of the advantages of argillites is their wide distribution throughout Russia, and there are also large reserves in the Southern Federal District and North Caucasus Federal District [1-5].

Argillites are characterized as a rock-like clay rock formed by the epigenesis and lithification of clays, not water-soluble. They undergo "dissolution" upon repeated wetting and drying or under certain mechanical stresses. The appearance of argillites from a typical deposit in southern Russia is shown in Fig. 1 [6-8].

Argillites are stone-like clay raw materials that slowly soak in water under certain mechanical stress, and dissolve upon repeated moistening and drying [9-11].



Fig. 1. Appearance of argillites.

The structural features, chemical and mineralogical composition and genesis of argillites determine all the technological properties of the rock. The mineral composition of argillites is diverse, but mainly there are hydro-micaceous and hydro-micaceous-kaolinite varieties (on average 50-70%), kaolinite (20-30%), chlorite (5-15%) and mixed-layered clay minerals, micas, quartz, feldspar, opal, iron oxides and a number of accessory minerals.

The texture of this rock is shell-like, often with inclusions of thin-plate compartments. Argillites are also characterized by oriented structures with parallel arrangement of flakes of clay materials. With prolonged moistening, the stone-like structure breaks up into separate particles along the planes of the stratification.

In terms of plasticity, argillites have low plasticity compared to refractory clays. However, rock studies have shown that the finer the degree of comminution and dispersion (fraction), the greater the plasticity of argillites.

Extrusion molding is the best manufacturing method for flat ceramic products. Since claystone-based products exhibit good bending strength of dried samples, they can be used to produce large-sized flat products.

Regarding the firing properties of argillites, depending on the degree of grinding and firing temperature, clays can be moderately sintered, while ceramic samples have water absorption of 2-6% without signs of overfiring. However, samples based on highly sintered argillites have water absorption of less than 2% without signs of overfiring. Ceramic samples based on argillites are also characterized by high strength.

The relevance of choosing argillites as raw materials for the production of high-strength ceramics is due not only to its widespread use, but also to the fact that argillites often become waste during the extraction and processing of raw materials for the production of expanded clay or re-mining of coal. A huge number of unused argillites dumps with a fraction of less than 10 mm occupy useful agricultural areas. Therefore, it is very modern and logical to use argillites in the ceramic industry [12].

2. METHODS AND MATERIALS

For the study, samples were collected from a typical argillites deposit in the Southern Federal District. Sampling was carried out in accordance with regulatory requirements. Laboratory and process samples of raw materials were dried to an air-dry state, then crushed in a laboratory jaw and hammer

crusher to the desired grain size. The next stage of the study involved selecting a mineralizing additive that is a strong fusible agent. Effective management of the high-strength ceramic production process requires a clear understanding of the processes occurring in the materials during firing, so microstructural analysis is essential.

The research relied on current regulatory and technical documents, generally accepted clay raw material testing methods, and proprietary techniques to achieve the highest possible accuracy. The technological research was guided by regulatory requirements, primarily GOST 21216-2014 "Clay Raw Materials. Test Methods," and also took into account the recommendations of leading experts in the field of clay raw material and ceramics research.

3. RESULTS AND DISCUSSION

Table 1 presents chemical composition of the studied argillites. In this analysis, it is necessary to take into account that oxides can exist both in various compounds and in a free state. This is important when predicting technological properties of raw materials.

Table 1. Results of chemical analysis of argillites, % by weight.

LOI	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	P ₂ O ₅	TiO ₂
5.59	61.16	17.53	6.48	0.77	1.86	0.05	3.57	1.08	0.14	0.98

As can be seen in the table below, the main component in the sample is SiO₂, its content is 61.16%. Silica forms fusible compounds with other components during firing, so it can be concluded that the more silica a sample contains, the more mica and clay minerals it contains. We also see that the sample contains 17.53% Al₂O₃. The aluminum oxide index is a quantitative indicator consisting of clay minerals – kaolin and hydrous mica. Since aluminum oxide is a refractory oxide, with its increase, the refractoriness of the raw materials increases and the sintering interval expands, which is important for large-sized products with a small thickness. Fe₂O₃ is contained in an amount of 6.48%, it is a strong melt and affects the color of the ceramic body, which must be taken into account when developing the firing mode for high-strength ceramic products. The maximum firing temperature of argillites is 1150 °C. The sintering temperature is also affected by the content of CaO and MgO, the content of these oxides up to 5% does not affect the color of the ceramic body. K₂O and Na₂O are alkaline oxides that are part of clay minerals.

After analyzing a large amount of scientific and technical literature and documentation, it was decided to select sodium tetraborate as the mineralizer [13-15]. To produce a high-strength argillites-based ceramic body, 0.5% of the mineralizer was added to the base fraction of 0-0.16 mm. Sodium tetraborate is ideal for reducing firing temperatures and intensifying the sintering process, which leads to reduced production costs.

The next step was to determine the pre-firing and post-firing properties. Table 2 presents the pre-firing properties of the studied grain compositions, including determination of molding moisture content, air shrinkage, and bending strength of dried samples.

Table 2. Pre-firing properties of argillite-based samples.

Marking	Molding-moisture content, %	Air shrinkage, %	Bending strength of dried samples, MPa
A-0.315	27.1	5.81	1.6
A-0.16	27.5	6.59	1.9
A-0.08	28.2	7.12	2.1
A-0.05	28.7	7.43	2.3
AB-0.16	28.0	6.94	2.1

Table 2 shows that all compositions are within the normal molding moisture range of 16-30% while exhibiting low air shrinkage. Based on the bending strength of dried specimens, all samples are classified as having low mechanical strength. This indicates that future argillite-based products have sufficient mechanical strength in a dry state and will not deteriorate during transportation and installation.

Firing is the foundation of high-strength product production. Firing gives the products properties that can be used to assess their quality. Firing properties include determination of fire shrinkage, average density, water absorption, flexural strength, and compressive strength. The resulting values are presented in Table 3.

The firing shrinkage index is not mandatory, but in our opinion, it is necessary to determine it. This indicator is important for determining shrinkage values, process calculations, etc. A direct correlation is observed for all samples: the higher the firing temperature and the degree of grinding, the greater the firing shrinkage.

The determination of strength indicators took place in the laboratory of the Department of Construction Materials using verified equipment.

As can be seen from the obtained data, the samples exhibit high strength, with bending strength ranging from 20.1 to 62.8 MPa and compressive strength ranging from 54.1 to 297.4 MPa (Fig. 3-4). Firing temperature influences the strength of the samples, resulting in a clear pattern: the higher the temperature, the greater the strength of the samples.

Table 3. Firing properties of argillite-based samples.

Marking	Firing temperature, °C	Fire shrinkage, %	Average density, kg/m ³	Bending strength, MPa	Bending strength of dry specimens, MPa	Water absorption, %
A-0.315	1000	7.65	1940	26.9	54.1	12.89
	1050	4.77	2200	32.5	67.4	4.02
	1100	5.32	2220	41.4	98.8	0.59
A-0.16	1000	1.90	1960	20.1	96.1	11.86
	1050	5.61	2220	38.2	117.3	2.98
	1100	6.19	2240	46.7	167.1	0.21
A-0.08	1000	2.15	1980	23.2	120.5	10.41
	1050	6.88	2240	43.1	187.8	2.64
	1100	7.42	2270	55.2	219.6	0.05
A-0.05	1000	2.91	1910	27.9	141.4	7.92
	1050	7.56	2260	51.1	218.5	0.81
	1100	8.19	2310	65.3	258.0	0.03
AB-0.16	1000	4.65	2000	31.3	149.3	7.80
	1050	8.01	2300	49.1	254.6	0.72
	1100	9.14	2320	62.8	297.4	0.03

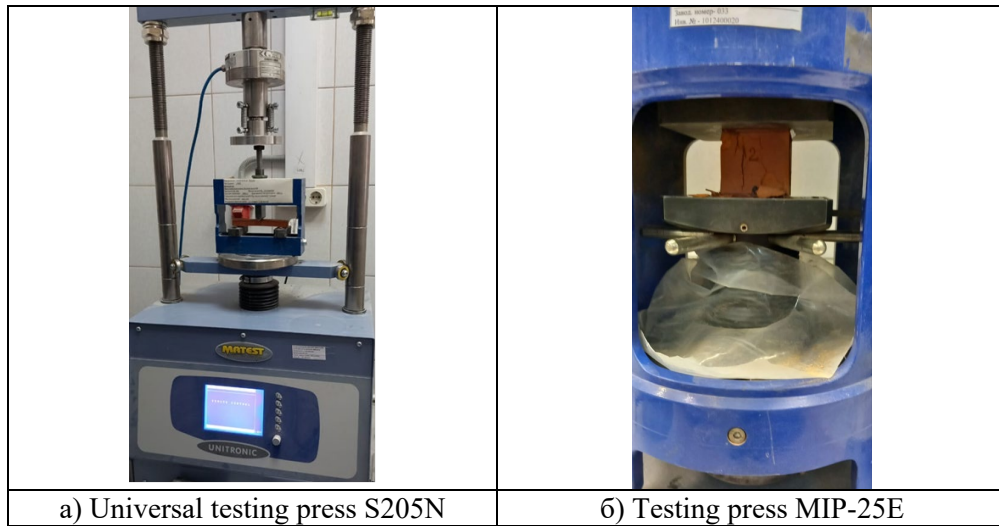


Fig. 2. Determination of strength indicators on laboratory equipment.

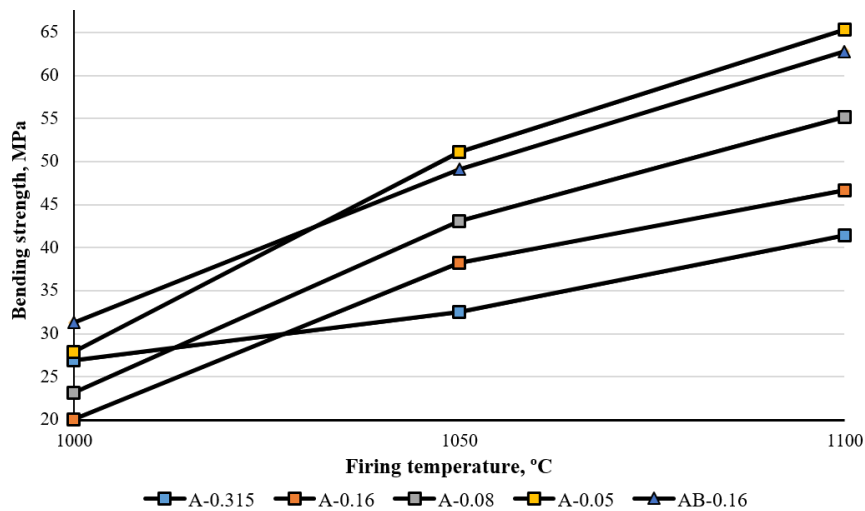


Fig. 3. Graphic dependence of the bending strength of grain compositions on the firing temperature.

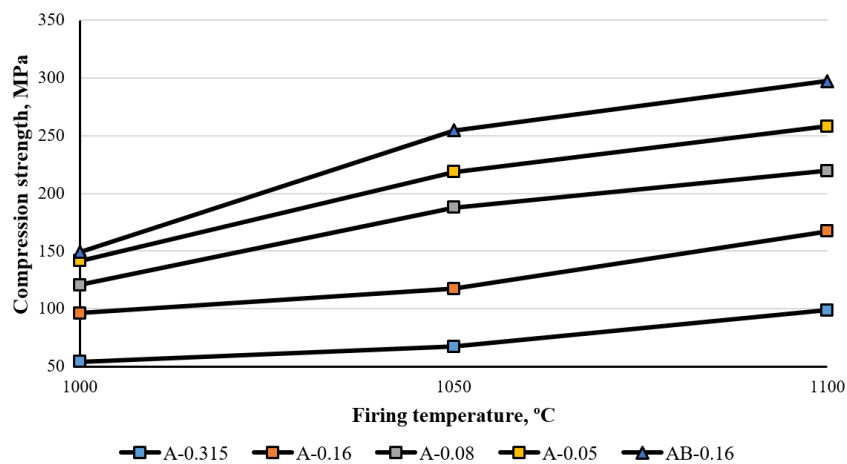


Fig. 4. Graphic dependence of the compressive strength of grain compositions on the firing temperature.

Fired argillite-based samples have high strength compared to traditional clays, but the maximum strength is observed in samples based on modified argillites. If we compare the obtained indicators, we see that the composition of AB-0.16 exceeds the strength characteristics of the composition of A-0.05, thus we can conclude that argillites do not need to be finely ground during mechanical preparation, but a fraction of 0-0.16 mm will suffice.

To obtain high-strength clinker ceramics, it is important that the water absorption is less than 5% (Fig. 5).

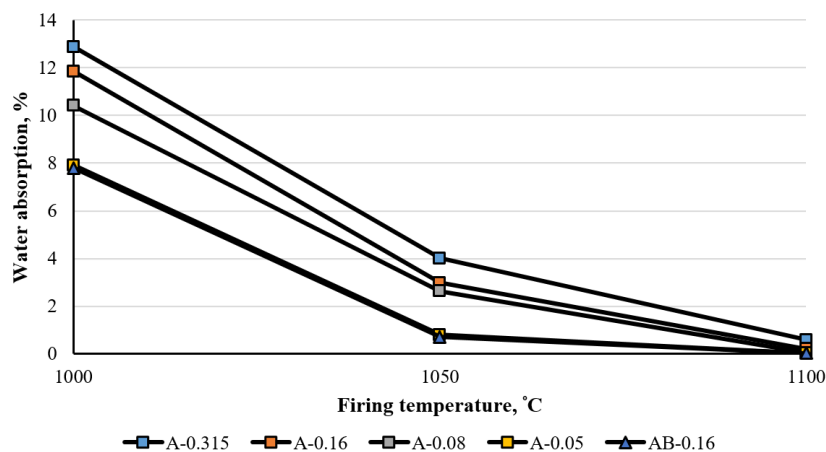


Fig. 5. Graphic dependence of the bending strength of grain compositions on the firing temperature.

The graphical dependence shows that water absorption at a temperature of 1050°C is less than 5% for all fractional compositions, but for AB-0.16 and A-0.05 it does not reach even 2%. At a firing temperature of 1100°C, it is closer to 0% for all fractional compositions. Achieving water absorption value of 0-1% has both its advantages and significant disadvantages. This suggests that high-strength argillite-based products will not absorb water and will be frost-resistant, thereby increasing their service life.

Comparing the performance of samples based on modified argillites with those based on argillites reveals several interesting factors. As we can see, samples based on modified argillites have greater strength, due to sodium tetraborate acting as a flux and intensifying the clinkering process. Thus, with the same grain size composition of 0-0.16 mm, it is possible to produce highly durable ceramic body with the addition of a mineralizer. The greater ceramic body strength allows us to increase the overall dimensions of the product and reduce its thickness for items such as roof tiles, siding, tiles, steps, window sills, etc.

The mineral composition of argillites and the firing temperature determine the specific phase and mineral composition of the ceramic body. The predominance of hydromicaceous and micaceous minerals, kaolinite, and feldspars results in increased potassium and aluminum oxide content, which facilitate the clinkering process and the formation of acicular and tabular minerals, significantly increasing the strength of the ceramic body. The content of these oxides in argillites is close to optimal for producing ceramics with a sintered, strong ceramic body at lower firing temperatures.

X-ray diagram of the ceramic body obtained from argillites with a grain size composition of 0-0.16 mm and fired at temperatures of 1000-1100 °C are shown in Figures 6-8. At a firing temperature of 1000 °C, the intensity of the quartz peaks decreases significantly, indicating the onset of its interaction with other minerals. The peaks characteristic of mullite become clearer. With an increase in the firing temperature to 1050 °C, the process of glass phase formation intensifies, which is evident from the increasing halo in the region of angles of 15-30 2 θ . At the same time, the peaks of mullite, spinels, and cordierite increase slightly, while those of quartz decrease. It should be noted that the water absorption of samples fired at a temperature of 1050 °C is 0.72-4.02%, i.e. the material is sufficiently sintered, and its structure can already be characterized as vitro-crystalline [16-20]. At a firing temperature of 1100 °C, judging by the halo in the region of angles of 15-30 2 θ , intensive melting of the entire system occurs, which is clearly visible under an electron microscope (Fig. 9).

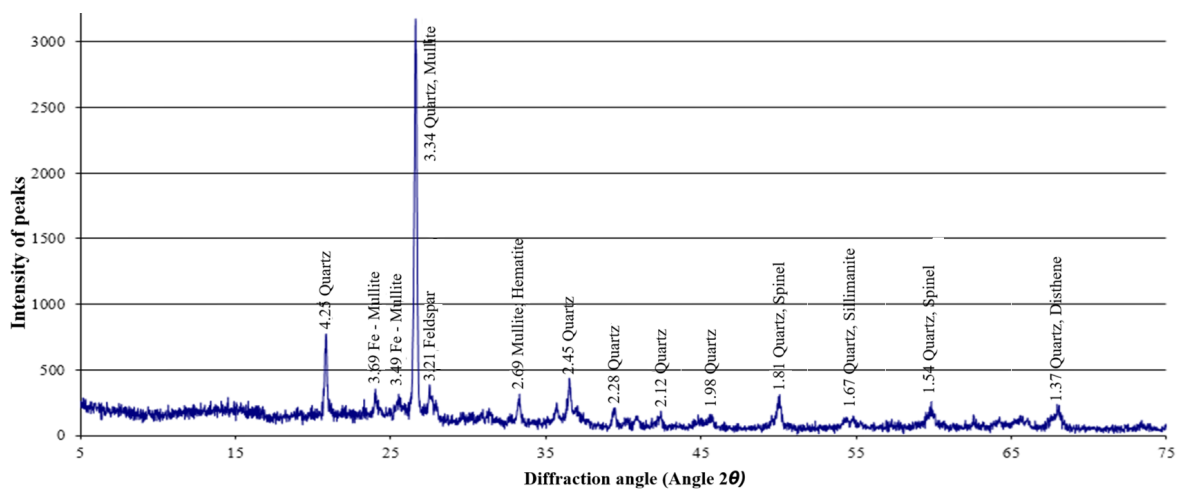


Fig. 6. X-ray diagram of argillites fired at a temperature of 1000 °C.

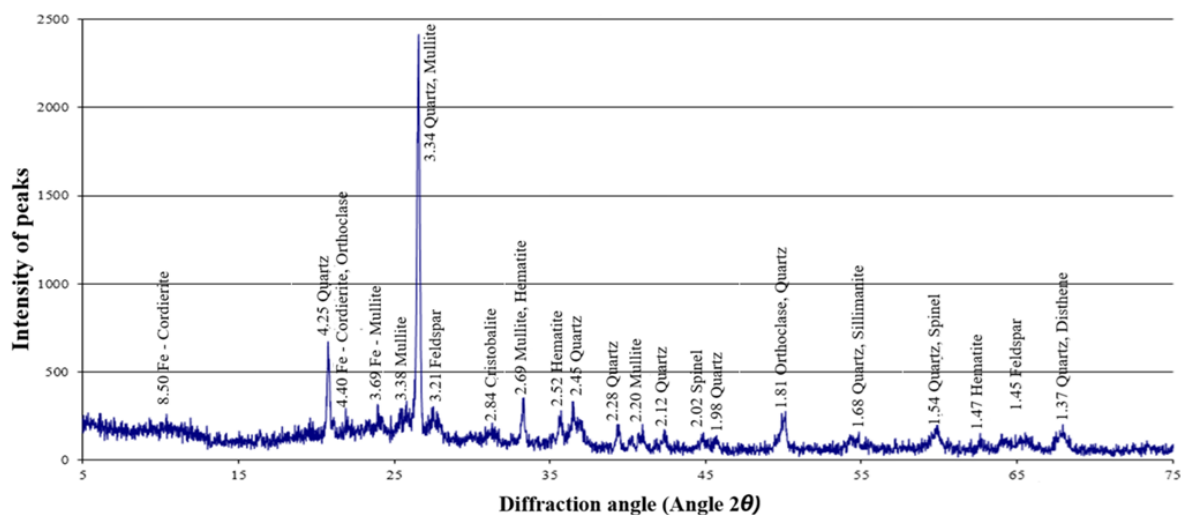


Fig. 7. X-ray diagram of argillites fired at a temperature of 1050°C.

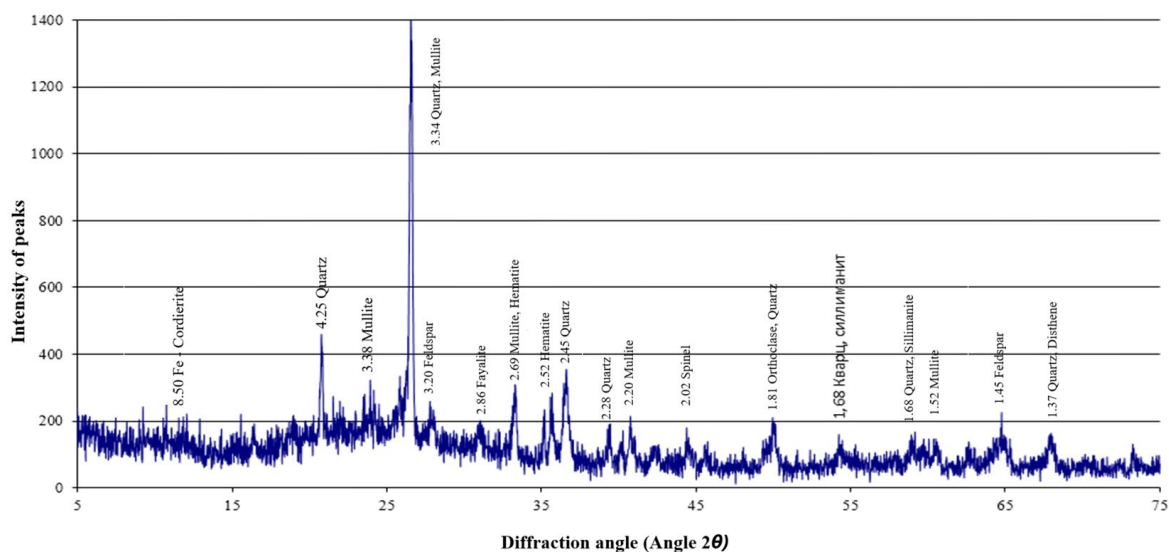


Fig. 8. X-ray diagram of argillites fired at a temperature of 1100 °C.

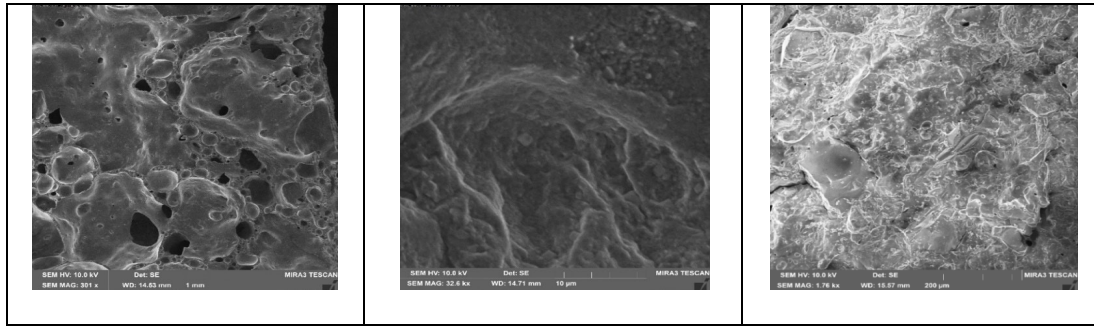


Fig. 9. Microstructure of argillites fired at a temperature of 1100 °C.

Based on the results of the research, it can be concluded that high-strength ceramics can be produced using argillites. The production process for high-strength ceramic products using argillites can be roughly divided into four stages (Fig. 10). Preparation of raw materials is the first stage. The primary objective is to properly grind the argillites to a specific grain size composition. This can be accomplished in several ways. For argillites that are not water-soluble and have low natural and quarry moisture (5-10%), it is best to use a semi-dry method, using crushing and impact methods. For argillites with increased moisture, natural drying under well-ventilated shelters is more efficient. Since argillites are lumpy, drying occurs relatively quickly. The first step, for argillite pieces up to 10-30 cm in size, is crushing, which is most efficiently performed using jaw crushers. Considering the strength and hardness of argillites, the service life of jaw crushers will be very long. Crushing dries the material slightly, while wet material only reduces crusher productivity. The output argillite size should be less than 10-30 mm. Crushing can be carried out directly in the quarry.

The second crushing operation is grinding. Grinding can be performed using two or a single piece of equipment. To achieve the required grain size composition distribution of 0-0.16 mm, hammer, ball, pendulum, centrifugal, airflow mill, and disintegrators equipped with separators for selecting the desired fraction with adjustable settings can be used. Using rollers to grind argillites is ineffective, as the resulting grains are flaky and lack fine argillites fractions. The grinding and separation process involves drying the raw material, which causes slight heating of the material during grinding.

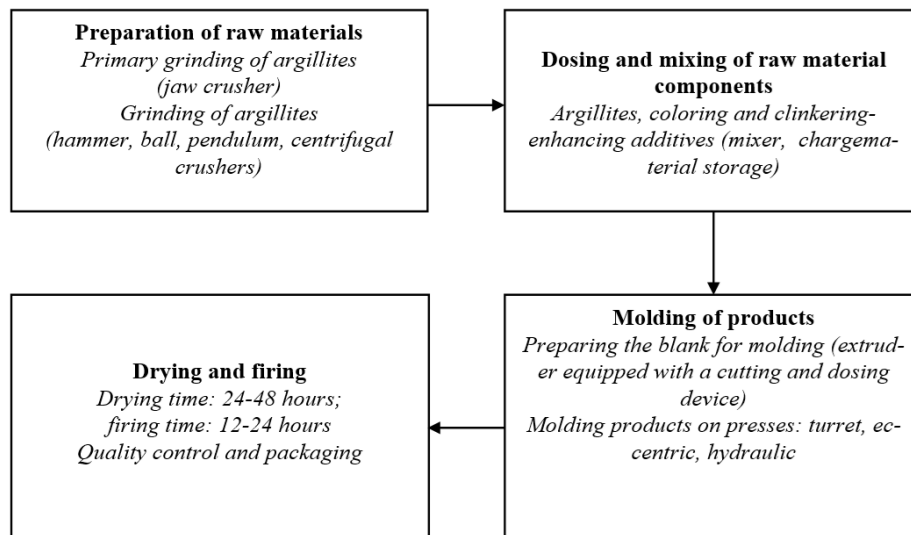


Fig. 10. Simplified flow chart for the production of high-strength flat ceramic products.

The next step in the process involves dosing and mixing the raw material components: argillites, water, coloring and clinkering additives. These additives are best added in powder form. Various mixers can be used for this purpose. The best option for thoroughly mixing the additives into the raw material is to install two mixers. The raw material then enters the charge material storage. Charge material storages can be of various types, including open, silo-type, or bunker-type. Conventional belt conveyors can be used to transport wet materials.

The blank is prepared for molding on an extruder equipped with a cutting and dosing devices. Molding can be performed on various types of presses, including turret, eccentric, hydraulic, and others. The choice of a specific molding machine depends on the shape of the future product, the moisture content of the mass, the productivity, etc.

After molding, the products are placed on drying shelves and transported (using mobile trolleys, a cradle conveyor, or a belt conveyor) for drying. The drying process should be handled with care to prevent product distortion. Traditional drying times for products range from 72 to 96 hours. However, for argillite-based products, this process can be significantly reduced to 24 to 48 hours.

Tunnel furnaces are mainly used for firing. These furnaces have more possibilities for automating the firing process, making them more cost-effective. The average firing time for argillite-based products is 12-24 hours, depending on the particle size of the argillite.

4. CONCLUSIONS

The tests conducted showed that it is possible to obtain a high-strength ceramic body based on modified argillites, which will have the following strength characteristics:

- bending strength from 49.1 MPa;
- compression strength from 254.6 MPa;
- water absorption less than 1%.

When developing a fundamental technology for producing a high-strength ceramic product, it is important to pay attention to the fractional composition, which should be 0-0.16 mm, to the additional component in the form of sodium tetraborate, which should not exceed 0.5% of the total raw material mass, and to the firing temperature, which should not exceed 1050 °C.

Based on the obtained results, it can be concluded that argillites are suitable for the production of high-strength ceramics. We consider the extrusion molding method to be the most preferable method for the production of ceramic products. This method is advantageous due to its cost-effectiveness, and it also allows for achieving higher raw material strength and, consequently, higher finished product strength.

REFERENCES

1. Kotlyar A.V., Lapunova K.A., Lazareva Y.V., Orlova M.E. Influence of argillite grinding degree on ceramic tiles and sidewalk clinker of low-temperature sintering. *Materials Science Forum*. 2018. 931. P. 526 – 531. DOI: 10.4028/www.scientific.net/MSF.931.526
2. Kotlyar V., Terekhina Ya., Kotlyar A., Yashchenko R. Evaluation of ailiceous opal-cristobalite rocks for the production of wall ceramics. *Lecture Notes in Networks and Systems*. 2023. 574. P. 2268 – 2282. DOI: 10.1007/978-3-031-21432-5_248
3. Kaigorodova E., Chugaev A., Lebedev V., Sadasyuk S., Gareev B., Batalin G. The Raduzhnoe Au–sulfide deposit (Northern Caucasus): geological settings, mineralogy, and sources of metals. *Geology of Ore Deposits*. 2022. 64. P. 257 – 280. DOI: 10.1134/S1075701522040031
4. Gualtieri S. Ceramic raw materials: how to establish the technological suitability of a raw material. *Archaeological and Anthropological Sciences*. 2020. 12. DOI: 10.1007/s12520-020-01135-w
5. Lazareva Y.V., Kotlyar A.V., Orlova M.E., Lapunova K.A. Water permeability of argillite-based ceramic tiles. *MATEC Web of Conferences*. 2018. 04072. DOI: 10.1051/mateconf/201819604072

6. Ning D., Ma Q., Ge W., Shao Z., Lei T., Xing H. Investigation of the microscopic properties of natural structured clay. *Frontiers in Earth Science*. 2023. 11. DOI: 10.3389/feart.2023.1312326
7. Bastida J., Pardo-Ibañez P. Applications of X-ray powder diffraction microstructural analysis in applied clay mineralogy. *Minerals*. 2024. 14. P. 584. DOI: 10.3390/min14060584
8. Avizovas R., Baskutis S., Navickas V., Tamándl L. Effect of chemical composition of clay on physical-mechanical properties of clay paving blocks. *Buildings*. 2022. 12. P. 943. DOI: 10.3390/buildings12070943
9. Rakhimova G., Stolboushkin A., Vyshar O., Stanevich V., Murat Rakhimov M., Kozlov P. Strong structure formation of ceramic composites based on coal mining overburden rocks. *MDPI Journal of Composites Science*. 2023. 7. P. 209. DOI: 10.3390/jcs7050209
10. Nurlybayev R., Zhuginissov M., Zhumadilova Zh., Joldassov A., Orynbekov Y., Murzagulova A. An investigation of the effects of additives and burning temperature on the properties of products based on loam. *Applied Sciences*. 2022. 12. P. 3352. DOI: 10.3390/app12073352
11. Batkhiev A. Mineral wealth of the Republic of Ingushetia. *Gornyi Zhurnal*. 2015. P. 9 – 13. DOI: 10.17580/gzh.2015.08.02
12. Levitskii I.A., Khoruzhik O.N. Relationship of properties, phase composition, and microstructure of clinker brick. *Glass and Ceramics*. 2021. Vol. 78. P. 193 – 199. DOI: 10.1007/s10717-021-00377-x
13. Manhart A., Vogt R., Priester M., Dehoust G., Auberger A., Blepp M., Dolega P., Kämper C., Giegrich J., Schmidt G., Kosmol J. The environmental criticality of primary raw materials – A new methodology to assess global environmental hazard potentials of minerals and metals from mining. *Mineral Economics*. 2019. Vol. 32. P. 91 – 107. DOI: 10.1007/s13563-018-0160-0
14. Borisov A.V., Kashirskaya N.N., El'tsov M.V., Pinskoy V.N., Plekhanova L.N., Idrisov I.A. Soils of ancient agricultural terraces of the Eastern Caucasus. *Eurasian Soil Science*. 2021. Vol. 54. P. 665 – 679. DOI: 10.1134/S1064229321050045
15. Zwaan F. Lower Cretaceous reservoir development in the North Sea Central Graben, and potential analogue settings in the Southern Permian Basin and South Viking Graben. *Geological Society, London, Special Publications*. 2028. 469. SP. 469.3. DOI: 10.1144/SP469.3
16. He T. Spectroscopy Methods in analysis of mineral composition. *Advanced Materials Research*. 2012. 476-478. P. 2617 – 2620. DOI: 10.4028/www.scientific.net/AMR.476-478.2617
17. Ma Zh., Xu L., Gong P., Chen Y., Zhang L. The thermal expansion characteristics of mudstone. *Thermal Science*. 2019. 23. P. 242 – 242. DOI: 10.2298/TSCI180718242M
18. Stolboushkin A.Y., Ivanov A.I., Fomina O.A. Use of coal-mining and processing wastes in production of bricks and fuel for their burning. *Procedia Engineering*. 2016. 150. P. 1496 – 1502. DOI: <http://dx.doi.org/10.1016/j.proeng.2016.07.089>
19. Orlova, M.E., Lapunova, K.A.: Characteristics of Jurassic argillites of the northwestern Caucasus as raw materials for the production of clinker tiles. *Construction Materials*. 2004. 8. P. 4-10. DOI:10.31659/0585-430X-2024-827-8-4-10
20. Uzhakhov, K.M., Kotlyar, A.V.: High-hollowness ceramic clinker stones: technology and application prospects. *Construction Materials*. 2024. 4. P. 49 – 54. DOI: <https://doi.org/10.31659/0585-430X-2024-823-4-49-54>

INFORMATION ABOUT THE AUTHOR

Orlova M.E., e-mail: marina.nekrasova.96@list.ru, ORCID ID: <https://orcid.org/0000-0002-5157-0586>, Don State Technical University, Assistant of the Department of Building Materials