Hyperpressed ceramic products based on industrial waste

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Abstract. The article discusses the features of the technology of production of ceramic products based on low-plastic clays and overburden. Physical and mechanical parameters of ceramic products obtained by hyperpressing with a pressure change from 10 to 100 MPa are determined. It is established that with an increase in the pressing pressure above 60 MPa, it is possible to obtain ceramic products with a compressive strength of up to 70 MPa and an average density of up to 2.1 g/cm³. The possibility of using high pressing pressures to produce high-strength ceramic bricks is justified. The results of the study of moisture loss during natural drying and physical and mechanical properties of raw products are presented.

With modern requirements for the architectural appearance and thermal protection of buildings, ceramic bricks remain the main structural and facing material in low-rise construction. In the total volume of low-rise housing construction, houses with walls made of bricks and small blocks currently occupy a leading position, which is facilitated by the presence of a developed material base. A significant advantage of this type of housing construction is the ability to give the building architectural expressiveness.

Various molding methods, such as plastic molding and semi-dry pressing, are used to produce ceramic materials with different shard structures. Despite the fact that ceramic bricks and stones are often produced by the simplest method of plastic molding, there is a promising possibility of obtaining effective ceramic materials by semi-dry pressing.

The technology of semi-dry pressing in the production of construction ceramics has been known for a long time. Usually, the pressing pressure does not exceed 25 MPa. Hyperpressing is considered to be a pressing pressure of more than 40 MPa. The advantages of the technology include the possible expansion of the raw material base through the use of local, including substandard, raw materials and industrial waste, which is important both in environmental terms and in a situation of significant depletion of high-quality clay reserves. The development of technology for the production of efficient materials based on local low-plastic clays, overburden rocks, as well as non-plastic raw materials and industrial waste using semi-dry pressing technology using high molding pressures (hyperpressing) implies a reduction in production specific energy consumption and a reduction in the duration of the technological cycle.

The influence of high pressing pressures on the physical and mechanical properties of raw and baked products was studied.

The research was carried out on clays of the Gryaznukhinsky deposit, with a low content of clay particles (10-12%) and a high content of dusty particles (up to 50%), the molding humidity of clay raw
materials is 22-24%. In addition, overburden rocks of the Tugnui coal mine, represented by mudstone, sandy loam and loam, were studied.

In the course of the work, the influence of pressing pressure on the processes of forming the structural strength and density of raw bricks, as well as the kinetics of moisture loss during natural drying of ceramic products, was studied. The pressing pressure varied from 10 to 100 MPa. The average density and compressive strength were determined immediately after molding, after one or two days of storing samples in air (table 1).

In addition to determining the density and strength of raw samples, the effect of hyperpressing on natural drying processes was studied.

Drying is one of the most important and complex stages in the production of ceramic products. Rapid evaporation of moisture from the surface of the molded product, that is, its drying, leads not to acceleration of the drying process, but to cracking of the raw material. Natural slow drying is preferable, especially since artificial drying requires high energy costs, and it does not exclude the possibility of marriage due to the appearance of cracks during shrinkage deformations.

| Name of the indicator | The pressing pressure of the material, MPa |
|-----------------------|-------------------------------------------|
|                       | 10 | 20 | 40 | 60 | 80 | 100 |
| The strength of the samples $R_c$, MPa | aftermolding | 1.3 | 1.8 | 3.0 | 4.1 | 5.2 | 6.0 |
|                       | after 1 day | 2.2 | 3.6 | 5.8 | 9.8 | 11.0 | 11.1 |
|                       | after 2 days | 2.6 | 3.9 | 8.0 | 9.8 | 11.0 | 12.8 |
| Sample density $\rho$, kg / m$^3$ | aftermolding | 1.92 | 2.01 | 2.17 | 2.22 | 2.25 | 2.28 |
|                       | after 1 day | 1.90 | 1.99 | 2.10 | 2.14 | 2.14 | 2.11 |
|                       | after 2 days | 1.89 | 1.97 | 2.09 | 2.13 | 2.14 | 2.11 |
| Molding humidity, % | 10 | 10 | 9 | 9 | 8 | 8 |
| Moisture loss during natural drying in 48 hours, % | 15 | 19 | 40 | 46 | 68 | 91 |
| including for the first day | 8 | 10 | 33 | 42 | 64 | 90 |

Attention should be paid to the amount of moisture loss, which is less than hygroscopic moisture in systems with a pressing pressure of more than 80 MPa. Therefore, at the time of pressing, up to 90% of the bound water is released from the molding moisture, which is held by weak physical forces and easily removed during storage at normal room temperature, and the remaining amount of water forms very thin films that allow you to include stronger short-acting physically bound forces in the structure formation process.

In hyperpressure samples intensify the process of drying it is due to the fact that hyperpressure there is a change in the forms of water, namely its transition to a less strongly bound state, the larger the level, the higher the pressing pressure, so within two days of natural drying the samples in air from hyperpressure systems removed from 40 to 90% moisture from forming, while in samples of conventional molding up to 19% and residual moisture in hyperpressure systems less hygroscopic moisture.

In contrast to natural conditions, where the processes of structure formation are stretched over time and elevated temperatures are present, short-term exposure to high pressures does not create conditions for the formation of phase contacts, although the resulting point contacts exceed the
strength values indicated in the literature for raw materials. Thus, in systems even with low-plastic raw materials, hyperpressing allows obtaining high raw strength, which accounts for from 13.7 to 17.3% of the final strength during sintering.

In addition, hyperpressing intensifies the drying process and eliminates artificial drying, while ensuring minimal humidity. This makes it possible to obtain high strength of raw samples (6 MPa) immediately after forming and up to 11.0-12.8 MPa (at a pressing pressure of 80 and 100 MPa, respectively) and natural air drying for two days. Samples obtained at a pressing pressure of more than 40 MPa lose from up to 90% of moisture in two days, while samples made at a pressing pressure of 10 and 20 MPa lose 15 and 19%, respectively.

This pressing process affects the rate of water evaporation during drying of ceramic products: with increasing pressing pressure, the drying rate increases (table 1). Although it should be noted that in the first hours, the kinetics of moisture loss depends slightly on the pressing pressure.

With an increase in the amount of clay minerals in the hardening system, more water is required, the swelling is more significant, but the drying process becomes more difficult and shrinkage deformations increase. The drying rate of wet clay materials is determined not so much by the rate of evaporation of moisture from the surface of the molded product, but by the rate of water migration inside the clay mass from the center to the periphery. Clay minerals prevent moisture from moving through their thickness, which significantly slows down drying.

You can increase the drying speed by introducing substances that improve the movement of water to the surface of the product, by forming through holes and using the hyperpressing method. In this study, the samples were dried under natural conditions for 48 hours.

The reduction of hydrate shells on dispersed clay particles and the involvement of shorter-acting bonds in the formation of structural strength leads to an increase in the raw strength of b during hyperpression.

The samples were fired after natural drying at a temperature of 950 °C, and the holding time at the maximum firing temperature was 2 hours. Figure 1 shows graphical dependences of the density and strength of the fired samples on the pressing pressure.

![Figure 1](image_url). Density and strength of the fired samples depending on the pressing pressure.

The high strength of hyperpressed samples is associated not only with an increase in the number of mechanical contacts and the involvement of surface-unsaturated bonds in strength synthesis, but also
with the acceleration of diffusion processes and chemical reactions therefore, a denser structure has a positive effect on sintering, and hyperpressing is indeed an effective way to obtain ceramic materials.

Based on the results obtained, we can conclude that on the basis of the studied raw materials that are not suitable for plastic molding, high-strength ceramic materials with a compressive strength of 12 to 74.1 MPa can be obtained by hyperpressing, which allows us to recommend this raw material for the production of bricks and the practically obtained strength of low-plastic raw materials meets the requirements for road bricks (grades 400, 500), that is, it allows us to obtain high-strength material.

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