Ceramic products based on modified agricultural waste

Aleksej Zhukov1,3, Andrej Ushakov1,*, Olimdzhon Rasulov2, and Ekaterina Mihailik1

1Moscow State University of Civil Engineering, 26, Yaroslavskoye Shosse, 129337, Moscow, Russia
2Khujand Polytechnic Institute of Tajik Technical University named after academician M. Osimi, 226, ave. Ismoil Somoni, Khujand, Tajikistan
3Research Institute of Building Physics Russian Academy of Architecture and Construction Sciences, 21, Lokomotivny pr., 127238, Moscow, Russia

Abstract. The current production status of building ceramics is based on the following realities. First, due to market conditions, the number of ceramics factories in operation has decreased significantly. Second, from 2019, taking into account the pace of housing construction related to the transition to new financing mechanisms, the production of ceramic bricks increased by 2-3% from 2019. Growth opportunities are associated with an increase in the thermal efficiency of ceramic products and masonry based on them. The aim of the research described in the article was the development of compositions for wall heat-efficient ceramics on the basis of loess-like low-quality clay using rice straw as a burnout additive and in particular to determine the optimal consumption of processed rice straw. The scientific novelty of the research consisted in the development of methods for selecting the composition of ceramic mixtures, optimizing their composition and demonstrating the influence of rice straw and rice straw ash on the properties of ceramic mixtures and the properties of products. Rice straw. 5–15% by weight of lint rice straw, which is incorporated into clay masses at the stage of their production and burns at a temperature of 200–300 ° C, burns out the mass and makes it porous, prevents shrinkage phenomena and ash contains up to 20% amorphous silica. Carbonates contained in clay dissociate during firing, interacting with amorphous silicon dioxide and forming various calcium silicates that strengthen the structure of the chip industry.

1 Introduction

The expansion of the range of ceramic wall products and the increase in their production are associated with increased demands on enclosing structures in terms of architectural expressiveness, thermal and operational properties of properties [1–3]. It is also necessary to take into account the state of production typical of this segment of the construction industry, market characteristics and the relationship between supply and demand. Such features include the transition to loams and other clays, which were previously considered to be of
limited use for ceramic production, a decrease in demand for ceramic bricks associated with the increased use of systems with insulation: Ventilated Facades or Plaster Facades [4–6].

The current state of production of building ceramics is based on the following realities. Firstly, as a result of market conditions and the promotion of multi-component systems for insulating facades and walls, the number of operating ceramic factories has significantly decreased from 557 to 310. Secondly, taking into account the growth in housing construction, due to the transition to new financing mechanisms, the implementation of programs preferential mortgages and programs to support the construction complex in the context of a pandemic, there has been an increase in the production of ceramic bricks by 2-3%. Growth opportunities are associated with an increase in the thermal efficiency of ceramic products and masonry based on them.

The state of the construction segment makes it necessary to look for new solutions that will make it possible, provided that the attractiveness of ceramic products as such (high durability, fire protection, strength, decorativeness, etc.) remains attractive in order to maintain competitiveness and heat-efficient types of products [7-9].

A possible direction for expanding the raw material base of wall ceramics is the use of siliceous Opoka-like rocks. Useful properties of Clay Zeolite-containing raw materials, its manufacturability are determined by the phase composition, crystal chemistry and structural features of its constituent minerals. The use of zeolite-containing clays or low-grade clays with the addition of zeolite-containing components has a fluxing effect on clay masses, improves sintering and mechanical strength of products [7–9].

One way of reducing the thermal conductivity of ceramic products and increasing the thermal resistance of masonry from them is to form a ceramic shard with a porous structure. Such a structure can be obtained by introducing extra-light aggregates that are sintered in the mass of a ceramic splinter during the firing of the ceramic, by the foam method or by the burnout additive method [10–13].

Various flammable additives are used in the composition of ceramic masses: coal dust. Sawdust, sifted polystyrene screening, but of particular interest is the use of rice straw. If we analyze the disposal methods for waste from rice production, we can conditionally divide them into two categories: destruction related to the reasons given above; rational use with or without preprocessing and preparation (Fig. 1).

Fig. 1. Ways of disposal of rice straw.
Rice straw. 5–15% by weight of lint rice straw, which is incorporated into clay masses at the stage of their production and burns at a temperature of 200–300 °C, burns out the mass and makes it porous, prevents shrinkage phenomena and ash contains up to 20% amorphous silica. Carbonates contained in clay dissociate during firing, interacting with amorphous silicon dioxide and forming various calcium silicates that strengthen the structure of the chip.

The purpose of the research described in the article was to develop compositions of wall ceramic products based on loess-like low-grade clay using rice straw as a burnout additive and, in particular, to determine the optimal consumption of processed rice straw.

2 Materials and methods

The types of clay used in the experiment with regard to the content of the finely dispersed fraction (less than 0.001 mm - 10.9–11.8%) belong to the group of coarsely dispersed clay raw materials. By the number of plasticity (average value - 8), they belong to moderately plastic and low-plastic clays. In terms of the aluminum oxide content (A12O3 less than 16%) in relation to the calcined substance, they belong to the group of sour clay raw materials. Due to the content of iron oxides (Fe2O3 more than 3%) - with a high content of coloring oxides. The average moisture content of the clay is 1.96%, the average density is 1.47 t / m³, the loosening coefficient is 1.14.

Rice straw is a fine-fiber material, ready for insertion into a clay composition, with the following technical characteristics: bulk density 180 - 200 kg / m³; average fiber diameter 50 - 100 μm; average fiber length 1 - 2 mm; flowability 45 °; ignition temperature (ignition) 200 - 220 °C.

The screw system is most widely used in plastic molding in ceramic brick factories, since it allows for the continuity of the process and at the same time works in a vacuum and a better homogenization of the paste is achieved. In laboratory conditions, with limited use of raw materials, the most acceptable device is a device operating on the principle of a piston extruder (Fig. 2).

![Diagram of a device for forming samples by the type of a piston extruder](image)

**Fig. 2.** Diagram of a device for forming samples by the type of a piston extruder: 1 - piston; 2 - rectangular body; 3 - hole; 4 - clay mass; 5 – emphasis.

Sample preparation procedure: The clay mass (4) with the required moisture content and the calculated volume is placed in a metal housing with a rectangular cross-section, moistened with machine oil (2). Install the stop (5). under the action of the piston (1) the clay mass is moved until it stops; Squeeze it together until there is an excess of mass in the control hole (3) of the body. Remove the stop and push the shaped sample out of the body.

Experiments to select the composition of ceramic mixtures using rice straw as a burnout additive and rice straw as the active mineral component were carried out on the basis of the mathematical planning and processing of the experimental results [14, 15] and the analysis of equations and the determination of the optimal cost were based on Carried out based on the analytical optimization method [16, 17].
3 Results

It can be seen from the graph that with the addition of rice straw (3.6.9 and 12%) to the composition of the clay composition, the density of the fired samples decreases, respectively, from 1.71 g/cm³ to 1.38 g/cm³ and to 0.95 g/cm³. At the same time, the porosity increases, respectively, from 33 to 45 and further to 60%, while the thermal conductivity decreases and the efficiency of the enclosing structure increases.

The state standard SNiP 23-02-2003 "Thermal protection of buildings" provides, with the above test results for density and porosity and taking into account the humidity of the environment in which the products are used, the thermal conductivity indicators, respectively, are about 0.6; 0.4 and 0.2 W/m°C.

Studies of the effect of adding rice straw to a clay composition on the change in its thermal conductivity were carried out at ISA MGSU by measuring the rate of temperature change during heating of a cylindrical probe immersed in a sample of a material of a certain shape, in accordance with GOST 30256-94.

The research results showed that when up to 10% of fluffed straw is introduced into the clay, the density of fired samples decreases from 1.7 to 1.1 g/cm³, and the thermal conductivity coefficient from 0.6 to 0.27 W/m°C. This means that the product, in terms of thermal conductivity, goes from the class of ineffective wall materials to the class of effective wall materials.

Having carried out a comparative analysis of the use of the effect of rice straw additives on the properties of clay or loam, we came to the conclusion that the addition of straw in an amount of 5-15% by weight sharply reduces the density of a ceramic shard with a significant loss of compressive strength table 1 and table 2.

Table 1. Comparative characteristics of clay compositions with the addition of rice straw.

<table>
<thead>
<tr>
<th>Clay Name</th>
<th>Average Density, Kg / M³</th>
<th>Compressive Strength, MPA</th>
<th>Water Absorption, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay + Straw (5%)</td>
<td>1580</td>
<td>11.1</td>
<td>17.3</td>
</tr>
<tr>
<td>Clay + Straw (10%)</td>
<td>1290</td>
<td>5.0</td>
<td>22.5</td>
</tr>
<tr>
<td>Clay + Straw (15%)</td>
<td>1010</td>
<td>1.6</td>
<td>30.4</td>
</tr>
</tbody>
</table>

Table 2. Comparative characteristics of clay compositions with the addition of rice straw or ash.

<table>
<thead>
<tr>
<th>Clay Name</th>
<th>Average Density, Kg / M³</th>
<th>Compressive Strength, MPA</th>
<th>Water Absorption, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay + Straw / Ash (5%)</td>
<td>1272/1326</td>
<td>7.26/6.3</td>
<td>26.91/28.7</td>
</tr>
<tr>
<td>Clay + Straw / Ash (10%)</td>
<td>1086/1286</td>
<td>2.25/5.7</td>
<td>33.24/27.5</td>
</tr>
<tr>
<td>Clay + Straw / Ash (15%)</td>
<td>882/1200</td>
<td>0.63/2.7</td>
<td>41.37/32.0</td>
</tr>
</tbody>
</table>

4 Discussions

Rice straw in the form of a fine-fibred loose mass and ash formed as a result of burning straw in the form of a highly dispersed granular mass have different effects on the processes of forming, drying and firing samples, as well as the properties of raw, adobe and shard.

Straw, is a non-woody plant matter and when the raw material is heated, already from 350 °C, it begins to smolder intensively to about 500-550 °C, emitting combustion products in the form of flue gases and decomposing, turns into ash. In this case, a reducing environment is formed in the sample, which affects the firing process and the formation of a shard.
Thus, straw is actually a burn-out additive, but it differs from the classic burn-out additives, both in the form of wood waste and waste from coal production. This difference lies in the fact that burning rice straw forms amorphous silica, which, under certain conditions, is able to interact with the products of clay sintering.

Ash obtained by burning straw under brick-making conditions in a thermal unit in an oxidizing environment consists of 89-91% silicon dioxide and 11-9% potassium, sodium, calcium, magnesium and iron oxides. In addition, the form of silicon dioxide is mostly crystalline. Thus, ash is actually an inert lean additive and its effect on raw and ceramic shards is somewhat different from that of straw.

Taking into account that straw is a more active component than ash in the studied compositions, the following ratios of clay and additives are accepted: in the composition clay - straw (scrap consumption from 3 to 12% by weight) in the clay - ash composition (ash consumption from 5 to 12% by weight.

The study examined the influence of the content of rice straw and ash (separately) on mold moisture, raw material density, drying shrinkage, density and strength of the shard as well as water absorption, thermal conductivity and frost resistance (saturation coefficient).

With an increase in the content of additives from 3 to 15% by weight of clay, the mold moisture content of the clay composition increases significantly with the addition of ash from 20 to 32% and with straw up to 41%. This high increase in mold moisture is due to the structural feature of the additives. Lean additives typically reduce the mold moisture of the clay composition. In contrast, ash increases moisture content due to its high dispersion, which approximates the dispersion of clay. Due to its fine fiber structure and high-water retention capacity, the straw further increases the moisture content of the mold.

It should be noted that with an increase in the molding moisture content of the clay composition, after drying, the density of the samples sharply decreases, the porosity increases, with practically unchanged shrinkage. When the samples are heated, in the first firing phase, the porosity of the samples with the addition of straw increases even more due to the release of gaseous products of straw combustion, the volume of which reaches 80%.

As shown above, the density of the samples when adding straw or ash to the clay composition sharply decreases. When 5% straw is added to the clay, the density of the composition decreases from 1575 kg/m³ to 1275 kg/m³, i.e. by 19%; with the introduction of 10% straw, the density decreases to 1085 kg/m³, i.e. by another 15%, and with 15% of the addition, the density decreases to 880 kg/m³. When ash is added to the clay, the density decreases more smoothly, and the 15% content reaches only 1100 kg/m³.

Obviously, with a decrease in the density of samples, their strength should also decrease in proportion. However, the loss of density in the samples with the addition of ash is much greater than that with straw. This is evidence that amorphous straw silica interacts with the components of the resulting shard, and is not inert.

The splinter's water absorption index is an indirect feature of its structure (Fig. 3). In addition to the indicators of density and strength, water absorption significantly affects the operational properties of the shard, namely water resistance and frost resistance. The type of porosity of the splinter affects its thermal conductivity (Fig. 4).

By reducing the density of the shard, both by adding straw and ashes, its water absorption is increased approximately equally. A high-water absorption in the examined samples is associated with the fine-pored structure of the obtained samples and the water resistance, and the frost resistance of the products mainly depends on the strength of the structure. The thermal conductivity index of wall ceramic products largely depends on the size and type of pores in their structure.
Fig. 3. Macrostructure of a shard of a composition of clay and ash of rice straw at 60-fold entrainment: a - clay 85%, ash 15%; b - clay 90%, ash 10%; c - clay 95%; ash 5%.

Fig. 4. Influence of the content of rice straw in the composition of clay masses on the density and thermal conductivity of wall ceramic products: 1 - average density; 2 - thermal conductivity.

5 Conclusion

The use of rice straw in the manufacture of bricks as a burnout additive and rice straw ash as a lean additive makes it possible to obtain ceramic products that meet the modern requirements for wall-enclosing structures. By firing samples of loess-like clay with the addition of rice straw and ashes from rice straw, a stable ceramic shard is created during
sintering, which consists of quartz and feldspar in the presence of new formations of aluminosilicates and calcium magnesium silicates. The use of rice straw as a technological additive in the manufacture of bricks creates a reducing environment during the firing process and contributes to a more complete sintering of the shard.

Optimal technological parameters are: degree of chopping (fluffing) of straw, mold moisture and plastic strength of the dough, drying and firing mode. The mold moisture content of the clay mixture varies between 20.0 and 24.5% depending on the straw content. When using an additive in the form of ash, a plastic molding process with a mold moisture content of 18.5-23.5% at a pressure in the extruder of 1.2-1.4MPa was also used. Firing temperature - 900 - 1000°C. If the straw content increases by up to 15%, the average density of a ceramic shard drops to 900 kg/m³.

The use of loess-like carbonate clays as raw materials with additions of 6 to 9% rice straw and 12 to 18% ash rice straw to obtain wall ceramics with low density and, consequently, high heat resistance, makes it possible to significantly expand the raw material base and huge use waste from rice processing.

References

1. A.A. Semyonov, State of the Russian market of ceramic wall materials Building materials 8, 9-12 (2014)
8. B.V. Tolpa, V.D. Kotlyar, Proceedings the second In the national conference “Clays minerals and layered materials”, 107 (2013)
17. A. Zhukov, E. Shokodko, Advances in Intelligent Systems and Computing, Springer, Cham 1116, 413-421 (2020) DOI: https://doi.org/10.1007/978-3-030-37919-3_40