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STUDYING THE PROPERTIES OF REFRACTORY PRODUCTS MANUFACTURED BY TWO-STAGE PRESSING UNDER INDUSTRIAL CONDITIONS

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The article deals with studying the properties of refractory masses made by two-stage pressing under industrial conditions in order to increase strength and slag resistance of chamotte bricks due to increasing density by ensuring uniform porosity throughout the volume of the product. Changing porosity when firing is less significant than changing porosity when pressing, therefore, the structure of the product is corrected by the initial mass of components

Keywords: refractory materials, chamotte, pressing, density, heat resistance

INTRODUCTION

At present there is a tendency to intensify a lot of processes that occur at high temperatures. This in turn raises the need to improve the operational properties of refractory products. In general, up to 70 % of refractory products are consumed in metallurgy [1]. Refractories are also used in manufacturing cement and glass, as well as in nuclear engineering and rocket science. Improving new methods of generating electric energy is also largely determined by the capabilities of the refractory products used [2]. So, the degree of industrialization of the country will be largely determined by the developed refractory industry.

The quality of refractory products used in practice determines to a large extent performance of the units and affects not only the quality of the products but also their cost [3,4].

The composition of the refractory mixture was previously determined. In previous studies, it was determined that the following composition is most appropriate: the main filler is the chamotte fraction of 2-3 mm, 60 %; 6 % small fraction chamotte (0,3- 0,4 mm); 34 % clay suspension based on clay of the Beloye Glinishche deposit.

The following rational technological mode of manufacturing refractory products was determined: pressing the charge samples was performed within 12 seconds, the basic (initial) pressure was 22 MPa, which was increased to 7 MPa after 7-8 seconds. Then the products are sintered at the temperature of 1 250 - 1 270 °C within 12 hours. The use in the composition of the binder clay of the Beloye Glinishche deposit allows achieving uniform porosity and increased product strength.

In order to increase strength and slag resistance of chamotte bricks due to increasing density by ensuring uniform porosity throughout the volume of the product, the samples were prepared using natural halloysite clay and broken fireclay brick minced to the fraction of 0,1-0,3 mm with the content, wt.%: 40,5 % natural clay, 59,5 % additives.

The use of such technology allowed reducing porosity (i.e., increasing density), which leads to increasing slag resistance and, in general, increasing the service life of such bricks.

EXPERIMENTAL PART. DISCUSSION AND RESULTS

The results of tests conducted in the Testing Laboratory of Engineering Profile (ILIP) and the Center of Heat-Resistant Alloys of Karaganda State Technical University are an experimental confirmation of the proposed method.

The components were weighed on a ShimadzuAX-200 analytical balance. The refractory mass was mixed on the laboratory roller grinding mills. The samples were made of the 250×120×65 mm size. The samples were prepared according to the known technology by pressing with the initial pressure of 22 MPa, followed by increasing to 27 MPa. The sintering temperature was 1 350 °C within 6 hours.

To assess the uniformity of density, the brick was cut into four equal parts, which were conditionally assigned numbers from 1 to 4. For comparison, the samples using only bentonite clay were made using the similar technology. The test results are shown in Table 1.

It was determined that the presence of halloysite clays renders a positive effect on the equalization of brick density due to its uniform distribution over the entire volume of the product and the homogeneity of properties.

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Table 1 **The samples density of refractory products with different compositions**

No.	Density of the refractory based on bentonite clay (reference)/g/cm³	Density of the refractory based on the mixture of halloysite and bentonite clay/ g/cm³
1	1,912	1,908
2	1,876	1,895
3	1,859	1,903
4	1,923	1,884

Slag resistance was estimated by the depth of slag flowing into the sample. For this, cylindrical holes with the diameter of 15 mm and the depth of 35 mm were made in the samples. Slag was poured into these holes after smelting 35HMFL steel in an induction steelmaking furnace. For comparison, the same operation was performed with the reference.

Then the obtained samples were placed in a Nabertherm LHT furnace and kept at the temperature of 1550 °C (slag was in the molten state) within 4 hours. After complete cooling, the samples were cut over the cross section, and the depth of slag penetration was studied. Points for determining the penetration depth were located radially around the central point. The results of studying slag resistance are shown in Table 2.

It is known that slag resistance of chamotte refractories depends on the chemical composition, structure, and density [5-6]. It should be remembered that slag can penetrate into chamotte bricks not only into open but also into closed pores due to corrosion. Therefore, to increase slag resistance, it is necessary to reduce not only the apparent porosity in the volume of the product but also the total porosity.

The tests carried out confirm the effectiveness of the proposed composition for manufacturing refractory products under industrial conditions.

It was previously shown that heat resistance of refractories is affected by the quality of bricks (porosity, strength, etc.) and the nature of the liquid metal interacting with the brick. In industrial conditions at the Parkhomenko KMZ LLP studies were conducted of the liquid metal effect on heat resistance of bricks manufactured under industrial conditions with the clay binder based on clay from the Beloye Glinishche deposit and the proposed technological modes. For this, bricks were immersed in the molten metal of various grades. The bricks were immersed on the melt mirror in a DSP-0.5 induction furnace.

The test samples were 265×114×65 mm bricks. The brick heat resistance is determined by the number of immersions in the liquid melt without destroying the brick integrity. The duration of the bricks staying in the melt was 15 minutes, after which the bricks were removed and cooled to the temperature of the workshop. After that, the bricks were again immersed in the liquid melt. The brick destruction into its component parts testified to the achievement of the limit of heat resistance.

The test results are shown in Table 3. The chemical composition of the melted alloys was determined in the chemical express laboratory of the Parkhomenko KMZ LLP.

As it is seen from the data of Table 3, the bricks have the lowest heat resistance when interacting with alloy steel (St 35HMFL). It should be noted that when using different alloys and grades of alloys, the temperature of the experiment was different, therefore, the alloys used in the experiments had different fluidity.

It is known that fluidity significantly affects heat resistance of refractories: the higher the fluidity of the melt, the greater the likelihood of slag entering brick pores and cracks.

Table 3 **Samples heat resistance depending on the melt nature**

Sample No.	Melt grade	Number of immersions
1	SCh10	51
2	St 35L	34
3	St 35HMFL	26

Compressive strength of the samples was determined depending on the forging pressure and sintering temperature used in the formation of the sample (Figures 1-3). In the first case, different pressures were used and samples were sintered at the temperature of 1 260 °C within 12 hours. In another series of experiments, the pressure of chamotte pressing was 22 MPa (basic) + 5 MPa (increase), and the sintering temperature changed. In the third series of experiments, the pressure of chamotte pressing was 22 MPa (basic) + 5 MPa (in-

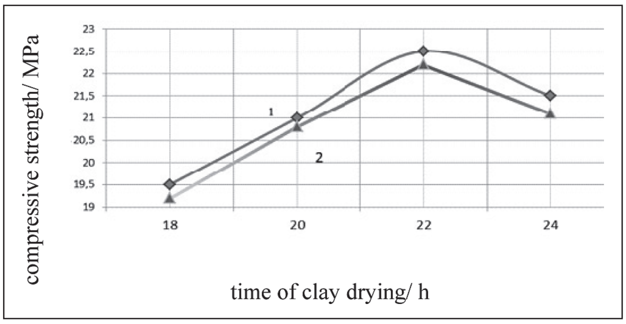

Figure 1 Pressure effect on the brick compressive strength: 1 – laboratory tests; 2 – industrial tests

Table 2 **Slag resistance of refractory products samples of the studied compositions**

No.	Point 1 (center)	Point 2 (10 cm from the center)	Point 3 (10 cm from the center)	Point 4 (10 cm from the center)	Point 5 (10 cm from the center)	Mean arithmetic value
Reference (only bentonite clay)	4,06	4,01	3,94	3,87	3,79	3,934
Experimental sample (bentonite clay + halloysite clay)	3,13	3,09	3,11	3,02	2,94	3,058

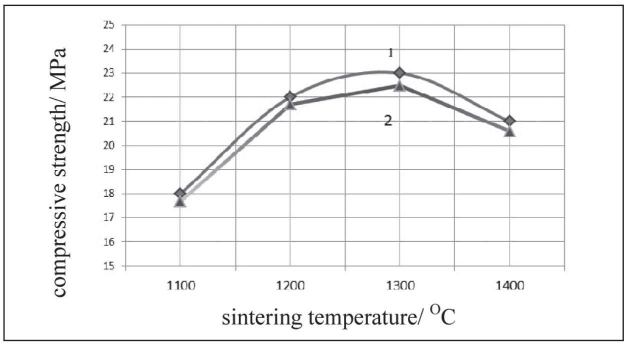

Figure 2 Sintering temperature effect on the brick compressive strength: 1 – laboratory tests; 2 – industrial tests

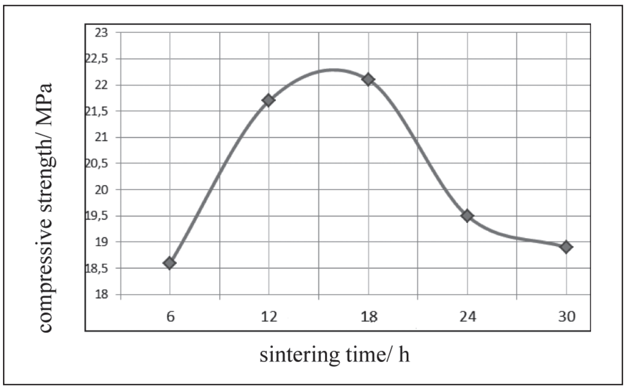

Figure 3 Sintering duration effect on the brick compressive strength under industrial conditions

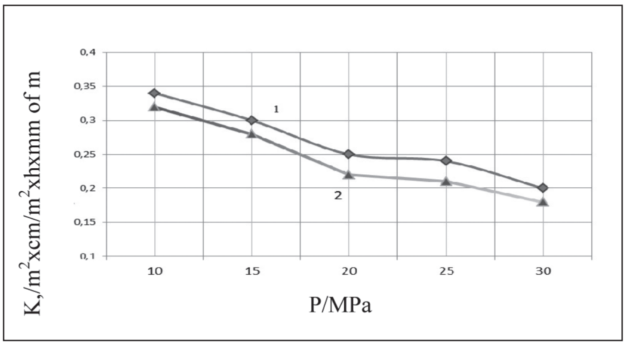

Figure 4 Pressure effect on brick gas permeability in the course of formation: 1 – laboratory tests; 2 – production tests

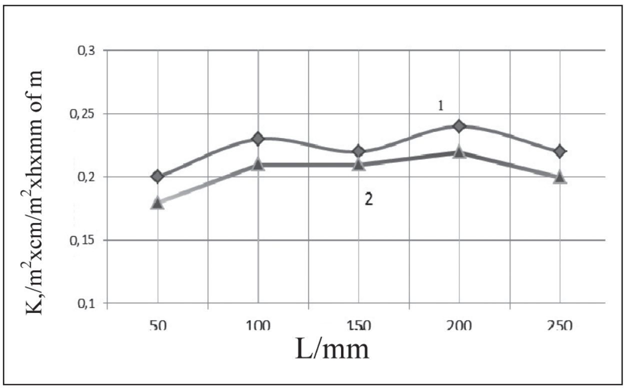

Figure 5 Gas permeability changing along the brick length: 1 – laboratory tests; 2 – production tests

crease) and sintering temperature 1 260 °C and the sintering time was changed.

It is obvious that for the formation of bricks, the forging pressure of more than 23 MPa, the sintering temperature of more than 1 350 ^{0}C and the sintering time of more than 18 hours negatively affect the mechanical properties of the obtained products..

There was studied the effect of pressure in the course of pressing refractories for their gas permeability (Figure 4). The samples were cut from the finished product, the shape of the samples was cylindrical, with the diameter of 50 mm and the height of 50 mm. It was shown that the optimal pressure on the mixture during brick formation was in the range of 20-25 MPa, with which increasing there was observed dense packing of the filler grains. The pressure increase in all experiments was 5 MPa.

The change in gas permeability along the length of the brick was also considered (Figure 5). It is obvious that the use of two-stage pressing in the process of product formation leads to equalization of gas permeability along the length of the refractory.

In Table 4 there are presented the data of the apparent density, gas permeability and porosity of the refractory depending on the forging pressure applied.

It is seen from the data in Table 5 that the use of two-stage pressing has a greater effect on the studied characteristics than only basic pressing.

In the process of firing the samples both in the clay binder and in the particles of chamotte, physical-and-chemical processes take place. It is known that at the temperature of the order of 150-200 °C, residual hygroscopic moisture is released. At this point, with signifi-

Table 4 **Apparent density, gas permeability and porosity of the bricks obtained in the laboratory and industrial conditions, depending on the forging pressure applied**

No	Pressure during formation/ MPa	Pressure increase during formation/ MPa	Apparent density of the products obtained in laboratory conditions/ g/cm^3	Apparent density of the products obtained in industrial conditions/ g/cm^3	Gas permeability of the samples obtained in laboratory condition/, m^3×cm/ m^2×h×mm Hg	Gas permeability of the samples obtained in laboratory conditions/ m^3×cm/ m^2×h×mm Hg	Porosity of the samples obtained in laboratory conditions/ %	Porosity of the samples obtained in industrial conditions/ %
1	19	0	1,72	1,70	0,25	0,23	23	21
2	19	5	1,82	1,83	0,24	0,22	20	19
3	22	0	1,83	1,81	0,21	0,20	21	18
4	22	5	1,90	1,91	0,20	0,19	19	15
5	25	0	1,85	1,82	0,20	0,18	17	16
6	25	5	1,92	1,93	0,19	0,16	13	12
7	28	0	1,93	1,91	0,18	0,15	14	14
8	28	5	1,94	1,94	0,16	0,14	11	11

cant formation of water vapor, it can condense on the products, which will lead to the appearance of defects such as cuts and cracks.

With increased residual moisture of the mixture, it is necessary to heat it more slowly. Then, when the mixture is heated to 450-550 °C in the clay binder, kaolinite decomposes releasing chemically bound water, which leads to slight linear shrinkage (less than 0,5 %). In the temperature range of 600–900 °C, a volumetric change occurs, which is uniform and corresponds to linear shrinkage of up to 2,5 %.

This also increases strength of the bricks. In this range there is also takes place oxidation of carbon impurities and sulfides, decomposition of calcium and magnesium carbonates.

Changing porosity during firing is less significant than changing porosity in the course of pressing, therefore, the structure of the product is adjusted by the initial mass of the components. Moreover, the structure of the starting components during firing changes qualitatively: the size of the pores increases, and their specific surface area decreases (Table 5).

Table 5 **Changing porosity of the refractory mass in the course of process operations**

Operation	Open porosity/ %	Pore sizes on average/mm	Strength/ MPa
Wet mass	21,7	1,12	11,3
After main pressing	19,5	0,87	17,9
After additional pressing	17,4	0,52	19,6
After firing	15,2	0,69	23,4

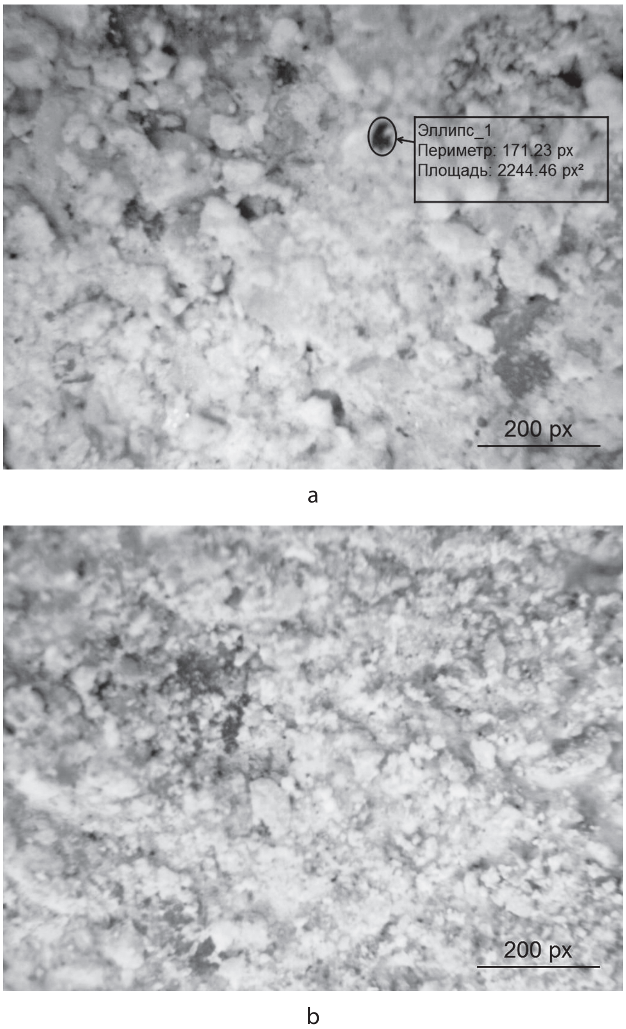

Figure 7 Refractory bricks surface structures at different stages, ×200: *a* – after firing; *b* – after firing with the use of additional pressing

The brick structures are presented in Figure 7. It is obvious that the amount and the volume of the pores with the use of additional pressing reduce significantly.

Thus, on the basis of laboratory and industrial studies, it was confirmed that the proposed composition and technological conditions made it possible to produce refractory products (bricks) with reduced and uniform porosity and increased heat resistance.

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Note: Responsible for the English language is Natalya Drak, Karaganda, Kazakhstan