Thin issues products of processing waste heaps as raw materials for ceramic wall products

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Abstract. Shown high perspectivity of production of wall ceramics products on the basis of fine-grained gob pile processed products with a high content of coal constituent. The characteristics of these materials, which are actually a ready-made ceramic fusion mixture, as well as the characteristics of the products obtained depending on the roasting temperature, are given. The established relationship between the various properties of the products obtained, the compressive strength of which is from 10 to 19 MPa, at a low density. Recommendations on the main technological parameters of production are given. It is emphasized that low prime cost of products is caused: excluding the costs of raw materials associated with the production and maintenance of fields; practical absence of costs for mass preparation; drying of products due to heat extraction from the furnace; lack of fuel costs necessary for roasting. It is pointed out that in the production of wall ceramics products based on fine-grained waste products of waste heaps, additional sources of income appear that are associated with a reduction in capital and current costs for the maintenance of dumps of FGPPP and the use of excess heat in various directions.

1 Introduction

Nowadays more and more attention for producing wall ceramics is attributed to different technogenic raw materials of coal variety. This is determined by several reasons, major of them are:

- the necessity to produce products in modern economic conditions at minimum net cost, that is achieved by reducing expenses on roasting and processing of raw material;
- a growing demand for products of high efficacy with middle density class 0,7-0,8 (less that 700-800 kg/m³) and heat conduction coefficient of bond in dry condition until 0,20 W/(m · °C). First of all, it concerns cellular porous ceramic stones from 2,1 to 14.9 NF in size:
  - changed economic conditions which made technogenic raw material more available for “brick makers” due to a range of reasons;
  - developed roaster furnaces for the raw material with high content of fuel component and with an opportunity to remove excess heat.

The usage of coal industry wastes as a raw material for producing wall ceramics has been known for a long time. In the Soviet Union this area was thoroughly investigated in 70-80’s of the past century [1-3]. There were major efforts put into laboratorial-technological researches. However, due to some reasons, this did not lead to practical appliance. Coal industry enterprises were not much interested in it – the main task was coal. Adjusting to brick factories had no economic sense for them. Independent gob pile development appeared to be quite problematic and costly for brick factories.

The situation has changed dramatically in the recent years. Coal enriching plants now consider coal enrichment by-products as goods and by all means are trying to adjust to a definite consumer in terms of characteristics and price [4-8]. Non-burnt gob pile is especially actively developed. The thing is that the coal content in them is from 10 to 25%. And the development of gob pile for coal extraction is today more economically profitable then underground coal mining. Only in the territory of Eastern Donbass there are about 500 mine heaps and enriching factories with mass about 600-700 mln. tons. In spite of the development, the heaps do not get smaller in volume, because during the process of extracting and enriching for 1 ton of clean coal it is necessary to take about 3 tons of by-products. Moreover, in the recent years the technologies of extracting and enriching coal have significantly advanced, as far as it is possible to regulate by-products properties according to coal constituent, grain composition, moist and so on.

2 Experiment

We have carried out researches on the possibility of receiving wall ceramics on the basis of fine-grained gob pile processed products with high content of coal constituent. On extracting coal during gob pile processing there are some kinds of materials formed. They are coarse-fractioned materials with the size of grains from 2 to 70 mm. They almost do not contain coal, they are separated into fractions (2–5; 5–10; 10–20; 20–40; 40–70 mm) and are used in construction industry. And fine-fractioned materials with the size of grains from 0 to 2 mm which do not have generally accepted names. They are divided into two types according to

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their fractional composition: fraction 0.5-2 mm, notionally referred to as prefilt, and 0-0.5 mm fraction, named by us as – Fine-grained gob pile processed products (FGPPP).

In greater degree due to its properties, fine-grained gob pile processed products appears to attract greater interest as a basic raw material for producing wall ceramics, because the prefilt is a leaner for clay masses. Fine-grained gob pile processed products can carry different amount of coal constituent, but in modern technologies it is mostly 20-25%. Our goal was to determine the possibility of receiving high efficacy wall ceramics on basis of fine-grained gob pile processed products. It is traditionally acknowledged that for producing brick of high quality, losses at roasting for coal wastes should not exceed 20% [1, 3]. However, there is a lack of experimental data on this topic and they are quite controversial.

The average chemical composition of fine-grained gob pile processed products of Eastern Donbass is presented in table 1. In contrast to clay raw material, fine-grained gob pile processed products possess high heat losses indices during roasting – 25-29% due to the coal constituent. If not taking into account this constituent, heat losses on roasting would change in the interval 5-8%. The content of SiO2 and Al2O3 without coal constituent is the same as in semi-acid clay raw material. The peculiarity is a high iron oxide and potassium oxide content that corresponds to mineral composition.

Table 1. Average chemical composition of fine-grained gob pile processed products of Eastern Donbass (% in mass).

<table>
<thead>
<tr>
<th>P.o.i.</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>CaO</th>
<th>MgO</th>
<th>SO3</th>
<th>K2O</th>
<th>Na2O</th>
<th>TiO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-29</td>
<td>34-38</td>
<td>13-17</td>
<td>7-12</td>
<td>1-4</td>
<td>0.5-2</td>
<td>0.4-1.5</td>
<td>3-4</td>
<td>0.5-20,5-1</td>
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</table>

The prevailing component of fine-grained gob pile processed products of Eastern Donbass is stone-like clay rocks of different lithification degree. Their main constituents are – chlorite, hydrous micas, micas, kaolinite, quartz, field spars, oxides and iron hydroxide (fig. 1).

The peaks of angles 9 and 18° indicate presence of hydrous micas and micas. The peaks of angles 6, 12 and 19° refer to the presence of chlorite and kaolinite. The peaks 3.34; 4.26; 2.58 Å signify the existence of quartz. A slight peak of 3.19 Å signifies the presence of field spars. The presence of montmorillonite in coalenriching products is still a question, but some authors point out its existence in coalenriching products.

The ash content of proper coal grains is 5–8 %, the volatile content is 3-4%. This is an important aspect for selecting optimal roasting regime of fine-grained gob pile processed products. Coal devolatilization happens at 300–350 °C, it is proved by exo-effect at 321 °C (fig. 2). Antracite flaming occurs at 630 °C, what is clearly evident by exo-effect and mass loss. However, on FGPPP based brick roasting in industrial furnaces this happens at the temperature of 700–750 °C.

![Fig. 1. X-ray pattern of typical fine-grained gob pile processed products of Eastern Donbass](image1)

![Fig. 2. Heat pattern of fine-grained gob pile processed products of Eastern Donbass](image2)

From the economic point of view the cost of FGPPP heat calory is 15-20 times lower in comparison with gas or pure coal. For example, the price for fine coal is 4000-5000 rubles per a ton, for power-generating coal is 3000-4000 rubles, for gas – 8000-1000 rubles per a ton, and for FGPPP is 100-200 rubles per a ton.

In fact, fine-grained gob pile processed products are prepared fusion mixture for producing wall ceramics. The main mass-preparing operation is making the mass in a mixing machine normally moisted for forming, mixing moisture content is 18–20 %. After the enriching process, the FGPPP moisture should be 10-14%. The plasticity is 9-12 units. Air shrinkage in comparison with clay is not really high, it is 3,5-4,5%. The average granulometric composition was measured with the help of a lazer diffraction particle size analyzer «NanoTec 2» (Germany) with water dispergation of the material and ultraonic machining (capacity 70 Wt, frequency 36 Hz). The average granulometric composition is presented in table 2.

Table 2. Results of granulometric FGPPP composition measurements

<table>
<thead>
<tr>
<th>Fractions contents, mm, %</th>
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<tbody>
<tr>
<td>0.5–0.25</td>
</tr>
<tr>
<td>0.05–0.05</td>
</tr>
<tr>
<td>0.01–0.005</td>
</tr>
<tr>
<td>0.005–0.001</td>
</tr>
<tr>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>4–6</td>
</tr>
<tr>
<td>6–10</td>
</tr>
<tr>
<td>21–25</td>
</tr>
<tr>
<td>23–27</td>
</tr>
<tr>
<td>28–32</td>
</tr>
<tr>
<td>7–11</td>
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</tbody>
</table>
Molding properties of FGPPP based mass are quite satisfactory for extrusional (plastic) type of products molding, as well as for a compressional one. However, a thorough choice of technological parameters of products molding according to the type of molding and types of products is necessary.

FGPPP with high coal constituent – more than 20% are of special interest. According to the coal constituent content (organic carbon) there are several types of rocks: low-carbon rocks ($C_{\text{org}} = 0–8\%$), intermediate-carbon ($C_{\text{org}} = 8–20\%$) and high-carbon ($C_{\text{org}}$ more 20%). It is acknowledged that if the carbon content is more than 20%, the strength of products will be quite low [1,2].

3 Results and discussion

The carried out researches gave us interesting results. On figure 3 there are interrelations of strength limit on compression, on bending and average density for FGPPP based plastic molding samples with a coal constituent of 21.8%.

![Graph](image)

Fig. 3. Interrelation of strength limit on compression, on bending and average density with roasting temperature

As it is evidenced, the received products possess quite acceptable for wall ceramics characteristics, which are significantly influenced by roasting temperature. So, the average density of solid-bodied products at the temperature of 900 °C is 1190 kg/m$^3$ and as the roasting temperature rises till 1050 °C it increases to 1480 kg/m$^3$. The strength limit on compression at the roasting temperature 900 °C is 10,5 MPa, and as the temperature rises till 1050 °C it increases to 18,9 MPa. The strength limit on bending also increases within the roasting temperature from 4,6 to 13,5 MPa. These indices are quite acceptable for load-carrying constructions. For achieving the average products density of 750 kg/m$^3$ at the roasting temperature 900 °C the porosity should be 37%, at the roasting temperature 1050 °C - 50%. Consequently, the strength limit on compression also decreases proportionally and it will be 5–10 MPa, that is also acceptable for highly-efficient ceramic stones.

Products based on fine-grained gob pile processed products have high porosity, that is 55% at the roasting temperature of 900 °C and 45 % at the roasting temperature of 1050°C. This significantly decreases heat conductivity of products. High porosity does not affect negatively frost resistance of products, as far as a brick carries enough amount of reserve pores of the size more than 200 mkm (fig. 4).

![Image](image)

Fig. 4. FGPPP based ceramic brick roasted at 900 °C (a) and 950 °C (b)

Special attention in the wall ceramics production should be attributed to roasting process. Products should be roasted at a regime with isometric timing and oxidizing environment at the temperature of coal constituent burning. Taking into account that the fuel content in FGPPP significantly exceeds the amount necessary for roasting, the furnace construction should provide an opportunity of extracting excess heat and gradual highly-controlled airing in the period of coal burning and carbon residue.

Under roasting temperatures of 1050 °C and higher, there are signs of overburning starting to appear, due to high iron oxide constituent that transfers out of a trivalent form into a bivalent one (fig. 5).

![Image](image)

Fig. 5. FGPPP based ceramic brick roasted at 1050 °C

Appearing at this process FeO is a strong fluxing agent, significantly increasing roasting process. This is illustrated by a rapid growth of fire shrinkage beginning at temperatures 1030–1050 °C (fig. 6).

![Image](image)

Fig. 6. Fire shrinkage of FGPPP based ceramic brick
4 Conclusion

The carried out researches have shown that basing on fine-grained gob pile processed products with high coal constituent (more that 20%) it is quite possible to produce lightweight wall ceramics with good physical-mechanical characteristics. In addition to that, the net coat of such products is minimal due to:

- excluding expenses on raw materials connected to the development and maintanence of fields;
- practical absence of mass preparation expenses;
- products drying by extracting excess heat out of the furnace;
- absence of roasting fuel expenses.

According to preliminary calculations, the net cost of conventional FGPPP based brick is 2.5-3.0 rubles. Moreover, FGPPP based wall ceramics production gives additional sources of income connected to the reduction of capital and operating expenditures for FGPPP heaps maintanence and the use of excess heat in quite various directions.

References