Use of bottom ash in the production of ceramic brick

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Abstract. The influence of the addition of ash residues from the processing of solid household waste from the Balakhani Industrial Zone in Baku on the properties of ceramic bricks in the Khirdalan and Karadag regions of Azerbaijan was studied. Ash residues were added in the amount of 10-50% of the mass. The physical properties of ash residues were studied - fractional, granulometric, radiological and toxicological compositions, as well as water absorption of ash bricks at different firing temperatures. The positive role of waste for obtaining wall ceramics with high performance properties was revealed, which corresponds to the regulatory requirements of GOST. It should be noted that the introduction of mineral additives has a positive effect on the characteristics of the ash brick. Among other ash-containing bricks at firing temperatures of 900 and 1100, the highest strength (22 MPa) is observed at 1100 ^{0}C with an ash content of up to 10%. As the ash content increases, the compressive strength at 900 ^{0}C and 1100 ^{0}C decreases.

1 Introduction

In connection with the gradual depletion of a number of natural minerals, on the one hand, and the accumulation of a huge amount of waste containing valuable useful components, on the other hand, the problem of industrial waste disposal is becoming increasingly important. [1-4].

Industrial waste (eg slag, fly ash, and brick, ceramic and marble waste) plays an important role in the sustainable development of the construction industry. These wastes as a partial replacement for building materials are very important because they provide many benefits, such as reduced consumption of natural resources and environmental pollution [5, 6]. Evaluation of these wastes as building materials that prevent the increase in waste stocks is the subject of many scientific studies [7-13].

Historically, fired clay brick is the most commonly used building material due to its low cost performance and the availability of clay throughout the country. Despite fired clay bricks' long-standing dominance as the building material of choice for housing, a number of environmental issues associated with its production raise concerns about future use. The production of fired clay bricks is an energy intensive process as the bricks are fired at temperatures above 1000 °C,

The use of bottom and fly ash in brick production will bring many benefits, such as the consumption of large volumes of waste, which will reduce the environmental problems caused by dumping this waste in landfills and ash dumps, improve brick properties and masonry productivity.

Previously, we made an attempt to develop bricks using bottom ash [14, 15]. The present work is a continuation of these studies.

2 Experimental part

Clay samples were taken from a brick factory in the Khirdalan and Karadag regions of Azerbaijan. Bottom ash - from the waste incineration plant of the Balakhani Industrial Zone in Baku. When MSW is burned, two main types of ash are produced: bottom ash and fly ash. Fly ash is 5-25% by mass and consists of fine particles that are removed by air pollution control devices; and bottom ash is 75-95% by weight; is the material that remains at the bottom of the combustion chamber. Clay-ash mixtures were developed with the addition of waste up to 50 wt. %. The ash was pre-dried and cleaned from metal and other inclusions.

The process of burning ash bricks was carried out in a laboratory electric chamber furnace. The maximum temperature reached 1100 °C during a 24-hour cooling cycle in a laboratory oven.

As additives, the mineralizers most active in calcium-containing masses were used - an alkaline solution of liquid glass - sodium silicate in an amount of 2%, which were introduced in the form of an aqueous solution into plastic molding masses. Sodium silicate content:
NaO = 7.8-8.2%, SiO_2 = 26.6-27%. Silicate modulus (molar ratio of SiO_2 to Na_2O) =3.41-3.51, density = 1.426 g /cm^3.

3 Results and discussion

After incineration of household waste, bottom ash is formed as a dark gray, granular, industrial waste in the form of a solid substance. The study of the physical and mechanical properties of this material and the determination of its application area seems to be an urgent task. The waste sample presented is a dark gray (blackish) solid material similar to gravel slurry when wet. It contains rock, pottery and other amorphous solid fragments of various sizes and compositions. In the natural case, the moisture content of the waste is W=17.38%.

Before starting the research, each of the samples was dried separately, and the granular content was checked by sieve analysis.

The chemical composition of ash residues is presented in **table 1.**

Table 1. Chemical composition of bottom ash, wt. %.

№	Samples	Chemical composition, %							
		p.p.p.	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Na_2O + K_2O
1	Sample №1 (initial)	18,05	38,20	8,38	3,68	20,48	4,64	1,65	4,67
2	Sample №2 (three fractions together)	23,65	27,00	6,79	4,27	26,38	6,04	3,29	2,58

As can be seen from table 1, incinerator ash contains CaO, SiO_2, Fe_2O_3 and Al_2O_3 oxides, similar to the composition of raw materials for brick production, this can become a possible replacement for raw materials in the production of ceramic bricks [6-10].

The granular composition of the bottom ash ranges from 40-0.00 mm. **(тable 2**). It is formed both in the form of crushed stone with a size of 40.0-5.0 mm, and in the form of sand with a size of 5.0-0.00 mm. The amount of the large-sized part is 50-55%. In its composition, substances of various shapes and various properties are clearly distinguished: iron crumb, ceramic and glass crumb.

It is not possible to determine the number of such mixtures. Sometimes it is the majority and sometimes the minority. Coarse-grained granules - 5.0-20.0 mm, casting density IC5-20=1930-2220 kg/m^3. The density of the embankment section, characterized as sand, consisting of fine-grained granules, varies within ϒ5, 0-0, 0=990-1060 kg/m^3.

The granulometric analysis of the bottom ash waste was carried out, sand (>0.25), fine sand (0.25-0.1), siltstone (0.1-0.01) and pelite fractions were determined.

Table 2. Granular composition of bottom ash samples.

№	Residues on sieves, by weight, %	Dimensions of openings of control sieves, mm					
		40-20	20-10	10-5	5-2,5	2,5-1,25	1,25-0,0
1.	Separate remnants: by weight, g %	270 5,4	1145 22,9	1183 23,66	872 17,44	264 5,28	1263 25,26
	Full balance, %	5,4	28,3	51,96	69,4	74,68	99,94
2.	Separate remnants: by weight, g %	378 7,5	1146 22,9	1229 24,5	851 17,0	281 5,6	1112 22,2
	Full balance, %	7,5	30,4	54,9	71,9	77,5	99,7

As can be seen from **table 3**, the number of granules with a size of 5.0-2.5 mm is 21.4% in batch I and 12.6% in batch III of the sample, and their sizes vary in size. It also shows that ash generation depends on the type of waste used in the combustion process, incineration, etc.; depending on the technological processes, they occur each time in a different form and composition. The composition of the sample studied in subsequent studies 2.5-1.25; 1.25-0.63; 0.63-0.315; <0.315 by combining the remaining fractions on dimensional sieves, a technological sample № 2 was developed.

Table 3. The results of the analysis of the fractional composition of ash samples

№ bottom ash batches	Fraction, % (dimensions, mm)							
	>20	20-10	10-5	5,0-2,5	2,5-1,25	1,25-0,63	0,63-0,31	<0,315
Sample №1	-	13,3	18,3	21,4	8,7	13,6	16,0	8,7
Sample №2	-	7,2	23,5	16,3	13,5	19,3	5,6	14,2
Sample №3	-	20,4	15,2	12,6	18,8	9,8	11,4	10,6

As can be seen from the analysis results, the chemical composition of both technological samples is similar. The content of calcium carbonate with losses at high temperatures in sample № 2 is higher than in sample № .1, due to the relatively high content of carbonate-containing scrap.

It can be seen from the research results that the differences in the chemical compositions of the samples from each other also depend on the initial form and type of waste burned.

The mineralogical composition of bottom ash (**table 4)** showed that the calcite form prevails - 61.8%, the rest are in the range of 4 - 9%.

Table 4. Mineralogical composition of bottom ash

Name of minerals	Mineral content , %						
	SiO_2 (*α-quartz*)	feldspar	clay	$Fe_3(PO_4)_2$	$CaSO_4 \cdot 2H_2O$ (gypsum)	$CaCO_3$ (calcite)	$Mg_3SO_4(OH)$
Compound , %	8,5	3,8	5,6	4,7	7,5	61,8	8,1

In the studied bottom ash samples, several components P_2O_5 - 2.21%, TiO_2 - 0.58%, MnO - 0.359% and Cl - 0.739% were also determined.

Table 5. Radiological and toxicological composition of bottom ash.

Sample	Specific activity of radionuclides determined in the composition of ash, Bq/kg			Aeff Bk/kg
	K-40	Th-232	Ra-226	
bottom ash	246±82	4±1	12±2	46,60

From **Table 5** shows that no artificial radionuclides were found in the sample, and the specific effective activity of natural radionuclides a = 46.60 Bq/kg, which is below the permissible level (the specific activity in building materials should be below 370 Bq/kg, RSN-31-93, (GOST 30108-94), and this material can be used in all construction sites without restrictions.

As established [9], the presence of a mineralizing additive is of great importance, which should ensure the formation of the required amount of the liquid phase, the role of which is to increase the degree of contact between the reacting solid particles and increase the rate of solid-phase interaction and the formation of the necessary crystalline compounds.

The study of the properties of ceramic samples was carried out according to standard methods [16, 17].

Figure 1 shows the dynamics of changes in the water absorption of ash bricks with an increase in ash content at 1100 ^{0}C. Bricks fired both at 800, 900 0C demonstrate similar properties with the addition of ash - water absorption increases.

The behavior of water absorption as a function of temperature with different bottom ash content is shown in figure 2.

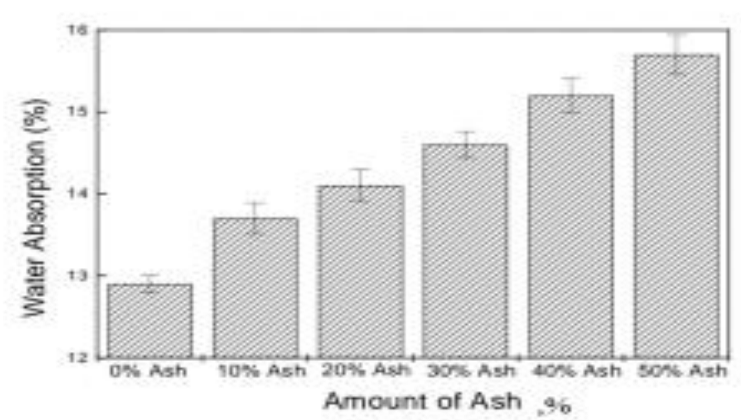

Fig. 1. Comparison of water absorption property of bricks fired at 1100 ^{0}C.

As can be seen from **fig. 2** for bricks containing 0% ash, as well as ash-containing bricks, as expected, with increasing temperature, water absorption decreases. The less water gets into the brick, the higher its durability and resistance to environmental influences.

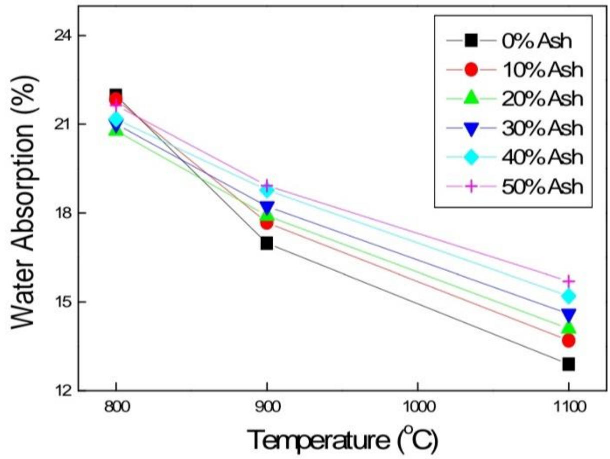

Fig.2. Comparison of water absorption of various samples of fly ash bricks at 800, 900 and 1100^{0}C.

Figure 3 shows a comparison of compressive strength at different temperatures. Both bricks fired at 900 ^{0}C and 1100 ^{0}C show a similar trend with the addition of ash. For all bricks fired at 800 ^{0}C, the compressive strength increases up to 20% ash addition and then decreases again. For bricks containing 0% ash, as expected, strength also increases with increasing temperature. This is due to the higher sintering action with higher diffusion rate at higher temperature. But for bricks containing ash, at 900^{0}C the strength becomes the lowest, and at 1100 ^{0}C the strength increases again. For bricks containing 20% ash, the highest strength (21 MPa) was observed at 800 ^{0}C. Among other ash-containing bricks, the highest strength (22 MPa) was observed at 1100 ^{0}C for a brick containing 10% ash. X-ray analysis of the ash confirmed the presence of a large amount of calcite ($CaCO_3$). At temperatures of 900 °C and above, calcite calcination can affect the strength of ash-containing bricks. As in ashless bricks, there is no calcite in clay, strength increases with firing temperature.

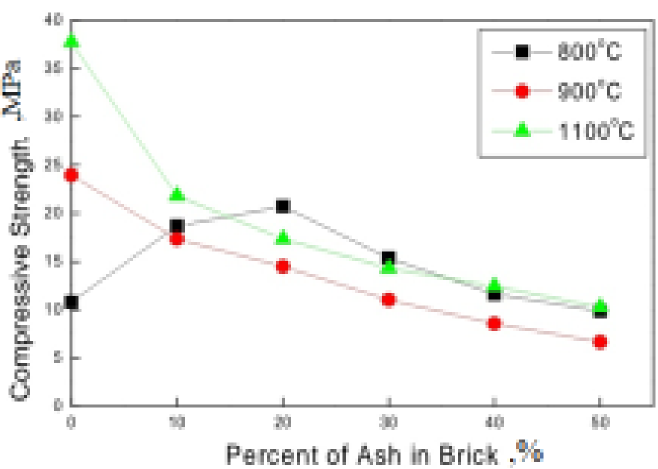

Fig.3. Comparison of compressive strength of bricks fired at 800, 900 and 1100 ^{0}C.

4 Conclusion

Thus, as a result of the study, a technique has been developed for producing bricks with the addition of ash residues activated with mineral additives, which allow you to adjust the physical and chemical properties of bricks.

The physical properties of ash residues of municipal solid waste of the Balakhani industrial zone in Baku were studied. The tables show the granulometric, fractional and radiological compositions of bottom ash.

The effect of adding bottom ash on the water absorption of ash bricks was studied. It has been established that with an increase in the content of ash residues in a brick, its water absorption increases, however, a comparison of the effect of the calcination temperature of an ash brick showed the same dynamics of a decrease in water absorption.

The results of the research create the possibility of developing innovative energy-saving, cost-effective and safe technologies, their improvement to obtain effective ceramic materials based on natural raw materials and technogenic industrial products.

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