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ИССЛЕДОВАНИЕ ОБРАЗЦОВ БЕТОНА, ПОЛУЧЕННЫХ ИЗ КЕРАМИЧЕСКИХ ОТХОДОВ

Г.И. Амануллаева, З.Э. Байрамова, А.М. Эминова

Гюнель Исаг гызы Амануллаева (ORCİD 0000-0003-3058-6703)*, Захра Эльхан кызы Байрамова (ORCİD 0000-0002-7165-7232), Арзу Мирпанах кызы Эминова

Кафедра химии и технологии неорганических веществ, Азербайджанский государственный университет нефти и промышленности, просп. Азадлыг, 16/21, Баку, Азербайджанская Республика, AZ1010
E-mail: emenullayevag@gmail.com*, quliyevazehra@mail.ru, a.e.eminova@gmail.com

Представленная научно-исследовательская работа относится к изучению свойств жаростойких бетонов, изготовленных с использованием отходов керамической плитки производства завода «Gilan Seramic». В работе конкретно показаны возможности использования керамических отходов и некоторые физико-химические свойства, применение и преимущества жаростойких бетонов. При получении бетона вместо природного сырья использовались отходы керамики. Отходы керамики замещают гравий 25%, 50%, 75%. Образцы бетона готовили по технологии производства бетона марки М400. Образцы бетона готовили в форме куба размерами 40×40×40 мм, прямоугольного параллелепипеда 40×40×160 мм и цилиндра 40×100 мм. Образцы бетона были проанализированы после 28 сут. затвердевания. Образцы бетона, полученные на основе отходов керамики, подвергали испытанию на оседание согласно нормативам, определяли среднюю плотность бетонной смеси, изучали прочность на изгиб, прочность на сжатие, термостойкость. В результате исследований установлено, что все полученные образцы бетона относятся к классу легких бетонов. Предел термостойкости приготовленных образцов бетона является одной из основных целей исследований. В данном исследовании использовалась муфельная электропечь модели BioBas MX8-13T с максимальной рабочей температурой 1300 ºC. При каждой заданной температуре образцы выдерживали 1-1,5 ч, а на следующем этапе под контролем постепенно охлаждали. После охлаждения структура образцов анализировалась, и образцы с положительными результатами подвергались следующему температурному испытанию. Образцы бетона по-разному реагировали на различные диапазоны температур.

Ключевые слова: отходы керамики, рециклинг, образцы бетона

RESEARCH OF CONCRETE SAMPLING OBTAINED FROM CERAMIC WASTE

G.I. Amanullayeva, Z.E. Bayramova, A.M. Eminova

Gunel I. Amanullayeva (ORCİD 0000-0003-3058-6703)*, Zahra E. Bayramova (ORCİD 0000-0002-7165-7232), Arzu M. Eminova

Department of Technology of Chemical and Inorganic Substances, Azerbaijan State Oil and Industry University, Azadlig ave., 16/21, Baku, Azerbaijan Republic, AZ1010
E-mail: emenullayevag@gmail.com*, quliyevazehra@mail.ru, a.e.eminova@gmail.com

The presented research work refers to the study of the properties of heat-resistant concrete made with ceramic tile waste produced by the "Gilan Seramic" plant. The possibilities of using ceramic scraps and some physico-chemical properties, application and advantages of heat-resistant concrete are specifically shown in this work. In the obtaining of concrete, waste ceramics were used instead of natural raw materials. Waste ceramic replaced gravel 25%, 50%, 75%. Concrete samples were prepared according to the M400 brand concrete production technology. Waste concrete samples were prepared in molds in the forms of a cube with dimensions of 40×40×40 mm, a rectangular 40×40×160 mm parallelepiped, and a 40×100 mm cylinder. Concrete samples were analyzed after

28 days of hardening. The concrete samples obtained on the basis of waste ceramics were subjected to the settling test according to the standards, the average density of the concrete mixture was determined, the bending strength, the compressive strength, and the temperature resistance were studied. As a result of the research, it was found that all the concrete samples obtained belong to the light concrete class. The limit of temperature resistance of prepared concrete samples is one of the main goals of the research. In this study, a BioBas MX8-13T model muffle electric furnace with a maximum operating temperature of 1300 ºC was used. At each target temperature, the samples were kept for 1-1.5 h, and at the next stage, they were gradually cooled under control. After cooling, the structure of the samples was analyzed, and the samples with positive results were subjected to the next temperature test. Concrete samples reacted differently to various temperature ranges.

Key words: waste ceramics, recycling, concrete samples

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INTRODUCTİON

One of the global problems in the world is waste disposal [1]. At present, 3 million 438 tons of waste have been accumulated in metallurgical industry, mining, energy enterprises, wood processing, construction material producing and other industrial areas in our republic. The amount of waste per person increased from 255 kg to 350 kg in 2020 [2, 3].

Saving construction materials, ensuring their reuse is the main component of economizing resources [4, 5]. The presented work is dedicated to the obtaining of heat-resistant concrete using secondary raw materials in order to save natural resources.

In many studies, the effect of high temperature on the change in physical and mechanical properties of concrete has been studied. The use of industrial waste as a coarse and fine filler in concrete has been the object of research in many studies [6-9]. Heat-resistant clay, kaolin and similar substances are used in the production of ceramics. There is enough ceramic waste in Azerbaijan, it is generated in production facilities, construction and demolition sites. The use of ceramic waste in this way makes it possible to produce more economical concrete. Also, the reuse of ceramic waste has a positive effect on saving primary natural resources and protecting the environment [10, 11]. In studies where ceramic waste is used in concrete mixtures, it was observed that ceramic has a positive effect on concrete compression resistance, alkali silica reaction, freeze-thaw resistance and impermeability [12-17].

The presented research work aims to increase the durability of concrete exposed to high temperature. For this purpose, ceramic waste is used as a substitute for gravel, and directions of reuse have been determined.

EXPERİMENTAL PART

The stages of preparation of all primary materials used in the experimental work are characterized, and experimental methodology in the production of heat-resistant concrete, determination methods for evaluating the properties of heat-resistant concrete are shown.

Waste ceramics, II type Portland cement, natural sand were taken as materials, and water was used as a binder.

Cement: CLASS A400 (CEM II/A-P 32.5R) (AZS 411:2010 (EN 197-1-2000) standard) type cement produced by Azerbaijan Norm Cement plant was used for the research. Ceramics: Recycled ceramics are the waste left during the production of "Gilan Seramic" LTD. 63.4% silicon 4-oxide occupies the largest part in the composition of ceramics. In addition, it contains potassium oxide, calcium oxide, and iron 3-oxide. Ceramics are characterized by low water absorption. The aggregate was washed before crushing to remove organic waste or any other extraneous impurities. The washed ceramics was dried for 24 h and then crushed. It was ground in a mill, sifted through sieves of different sizes and divided into fractions. Sand from the "Guba sand-gravel quarry" was used as natural black sand (GOST 8735-88).

The samples were prepared as follows: cement, ceramic scraps, sand, gravel were sieved and fractionated.

Then the raw materials used were weighed on an electronic scale with an accuracy of 0.01 g. The 2-7 mm fraction of ceramic waste was used in the research work.

Water is present in concrete as a binding material. Water meeting the requirements of GOST 23732-2011 standards was used for the preparation of concrete composites (GOST 23732-79).

Concrete samples were prepared in different ratios. They were obtained according to the production technology of M400 brand concrete (Table 1) [18, 19].

Table 1

The proportion of preparation of concrete samples based on ceramic waste

***Таблица 1.* Доля приготовления образцов бетона на основе керамических отходов**

Concrete samples	Percentages of recycled Aggregates, %	Mix proportions g/sm^3					
		Water/cement	Cement	Water	Rude Aggregate		Fine aggregate
					Natural raw materials	Waste ceramics	Natural raw materials
0	0	0.656	0.625	0.41	0.63	0	0.94
C25	25	0.656	0.625	0.41	0.47	0.16	0.94
C50	50	0.656	0.625	0.41	0.51	0.51	0.94
C75	75	0.656	0.625	0.41	0.16	0.47	0.94

Concrete samples were prepared in molds in the form of 40×40×40 mm cube, a 40×40×160 mm rectangular parallelepiped, and a cylinder with dimensions of 40×100 mm. Concrete samples were analyzed after 28 days of hardening. The settling test, determination of average density, bending strength limit, compressive strength limit, and temperature resistance of the concrete samples obtained on the basis of waste ceramics were studied according to the methodology.

Determining the ease of spread of the concrete mixture by settling (cone) test: The spread test was carried out according to the GOST 101813.3-81-2014 standard. A mold, i.e. a settling cone, a non-porous plate, a measuring scale, and a fixing rod were used for the settling test. The test mold is a truncated cone with a height of 30 cm, a bottom diameter of 20 cm, and a top diameter of 10 cm (GOST 10181-2000). The fixing rod has a diameter of 16 mm and a length of 60 cm. The inner surface of the mold is cleaned and degreased. It is placed on a smooth horizontal non-porous board. The mold is filled with the prepared concrete mixture about 3 times. The obtained results were determined according to the well-known literature [20], which gives the classes of concrete on collapse.

Determining the bending strength limit: The tests were carried out on samples in the form of a rectangular parallelepiped with dimensions of 160×40×40 mm. The bending strength limit (s) is determined according to the formula given with an accuracy of 0.5 MPa [20].

$$\sigma = \frac{3Pl}{2bh^2}$$

In the formula: l is the distance between the supports of the testing apparatus (mm), P – the destructive load (N), h – the thickness of the sample (mm), b – the width of the sample (mm).

Determination of the compressive strength limit: The compressive strength limit of concrete samples is determined according to GOST 31180-2003 and EN 196-1 2005. Samples for compression tests are prepared in cube-shaped molds with dimensions of 40×40×40 mm. The sample is placed in a special compressing unit of the YAW-300D testing machine. The conditions of the test are determined by the computer. The loading speed of the samples should be within the limits of 0.6±0.4 MPa/s. The compressive strength limit of concrete samples (σ_S, MPa) is calculated with an accuracy of 0.01 using the following formula:

$$\sigma = \frac{F}{S};$$

where σ – strength limit in compression (MPa); S – cross-sectional area of the concrete sample (mm^2); F – strength limit in maximum compression (N).

Determination of the average density of the concrete mixture is carried out according to the GOST 12730.2-78 standard. Knowing the unit weight of the concrete sample is very important, especially in large structures. The density of concrete depends on the amount of inert materials added to it (GOST 10181-2000). To perform this test, the volume of the container must be known. Either a container of known volume should be used (preferred to be tested in a laboratory using the water method) or the volume of the container should be calculated using the formula for the volume of a cylinder. The inside of the container is moistened and excess water is poured out. The mass of the empty container is measured on the scale to the nearest 0.1 g. The container is placed on a flat and firm surface. The container is filled with 3 equal volumes of concrete and each layer is struck and air is removed. The last layer should not be filled too much. If there is excess concrete, it is removed with a trowel. The excess concrete on the outside of the container is cleaned with a cloth, sponge or brush, and then the concrete-filled container is weighed. It is calculated for each sample separately using the following formula.

$$D = \frac{\left(M_f - M_e\right)}{V},$$

where D – Unit Weight, M_f – mass of full container, M_e – mass of empty container, V – Container volume.

Determination of the degree of temperature resistance GOST 12.1.033 provides thermal test methods for concrete structural elements. A BioBas MX8-13T model muffle electric furnace was used in this study. Concrete specimens were studied at seven temperature categories, namely 23, 150, 300, 500, 700, 850 and 1000 °C [21].

The samples were exposed to high temperatures in a muffle electric furnace, and after reaching the target temperature, all samples were kept at this temperature for 1-1.5 hours. The temperature inside the furnace is recorded by internal thermometers and the heat loading rate in this case is adjustable 2 °C/min. After the thermal loading was completed, the samples were first cooled to 300 °C at a constant rate and then left in the oven to reach ambient temperature.

RESULTS AND DISCUSSION

The rate of settling of the concrete mixture is one of the factors affecting its use. The settling results of concrete samples made with ceramic aggregate are given in Table 2.

Table 2

Density and settlement results of concrete samples made with ceramic aggregate

***Таблица 2*. Плотность и результаты осадки образцов бетона, изготовленных с керамическим заполнителем**

Sample	Recycled ceramic aggregate, %	Density, kg\m^3	Settling of cement, mm
0	0	1450	100
C25	25	1423	110
C50	50	1337	125
C75	75	1312	140

When concrete is poured into molds, flowability is important so that the mold easily takes its shape. When the value of this fluidity is low, it affects the amount of air voids in the concrete forms and the air voids increase. These pores reduce the strength of concrete. In order to eliminate air gaps, the duration of the vibration process should be increased during the pouring of concrete into molds. This means additional energy loss. As a result of the settling of waste ceramic-based concrete, the amount of waste in the total mass has already decreased. In C25, C50, C75 concrete samples, the value of subsidence was 110-140 mm. This is explained by the fact that the ceramic aggregate does not have a very porous structure. These samples can be attributed to the S3 class due to their collapse.

The density of concrete samples was studied according to the methodology. The highest result was 1423 kg/m^3 in sample number C25 (Table 2). According to the obtained results, it can be said that the samples received belong to the light concrete class according to their classification. The use of lightweight concrete in construction is very useful. It improves the thermal and acoustic properties of concrete. It also reduces the weight of the structure during construction. This is especially important in the construction of tall structures and in areas with high seismic activity.

The compressive strength of concrete gives an idea about its mechanical properties. Based on the results of these experiments, it is possible to know whether the work is going well. The compressive strength of concrete depends on factors such as the characteristics of cement, the ratio of cement to water and the quality of inert materials used in concrete.

Table 3

Compressive and bending strength limits of concrete samples made with ceramic aggregate

***Таблица 3.* Пределы прочности на сжатие и изгиб образцов бетона с керамическим заполнителем**

Sample	Proportion of recycled ceramic aggregate, %	Compressive strength limit, MPa	Bending strength limit, MPa
0	0	12.1	5.5
C25	25	7.175	2.22
C50	50	8.193	5.07
C75	75	5.556	2.22

The results of compressive strength analyzes of concrete samples are shown in Table 3. A good result was obtained in the C50 sample. In this sample, the compressive strength limit was 8.193 MPa, and the bending strength limit was 5.07 MPa.

The effect of the amount of waste used on the flexural strength limit of concrete samples was studied. The flexural strength limit is one of the main and important mechanical properties of concrete and an indicator reflecting the deformation of concrete structures under heavy loads. This limit indicates the limit of tensile and fracture toughness. The results of tests of concrete samples with ceramic additives are shown in Table 3.

The flexural strength of concrete samples with ceramics varies between 2.22 MPa and 5.07 MPa. In concrete sample No. C25, the indicator was 2.22 MPa. This figure is considered to be low compared to the waste unused sample and received a low score of 59.6%. The best indicator was recorded in concrete sample No. C50, which replaced natural raw materials with 50% of ceramic scraps. This indicator was calculated as 5.07 MPa. If we compare with the control sample, we will see that this indicator has decreased by 7.8%.

Concrete samples of each proportion were examined at seven temperature categories, namely 23, 150, 300, 500, 700, 850 and 1000 °C. Temperatures of 23 °C and 150 °C were taken as ambient and furnace temperatures, respectively. Other temperatures were considered high temperatures.The effect of the amount of waste used on the temperature resistance of concrete samples showed a different response. Initially, after reaching the temperature of 150-300 °C, no changes were observed in the structure of the samples kept in the oven for one hour, they kept their shape completely. In the next stage, the samples were exposed to a higher temperature of 500 °C and kept in the furnace at this temperature for one hour. As in other experiments, after reaching the target temperature, it was cooled to room temperature at a constant rate. The samples were exposed to the specified temperature for one hour. According to the results of the experiment, no changes were observed in the structure of all the samples exposed to 300 °C, 500 °C, 750 °C, concrete samples were resistant to these temperatures. Changes in the structure were observed after reaching the temperature of 1000 °C. Concrete samples were resistant to temperatures of 850 °C. When the temperature of 1000 °C was reached, cracks appeared in the concrete samples.

CONCLUSİONS

In order to save natural raw materials and recycle construction waste, concrete compositions were prepared by replacing natural raw materials by 25%, 50%, 75% on the basis of waste ceramics. The settling test of the received concrete samples was carried out according to the standards, the average density of the concrete mixture was determined, the bending strength limit, the compression strength limit, and the temperature resistance limit were studied. The best indicator was recorded in concrete sample № C50, which replaced natural raw materials with 50% of ceramic scraps. Concrete samples were resistant to 850 °C temperature.

The authors declare the absence a conflict of interest warranting disclosure in this article.

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