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Use of concrete scrap as a coarse aggregate for reinforced concrete products

U. Askarbekkyzy*

Satbayev University, Almaty, Kazakhstan

**Corresponding author: umkaaskarbekkyzy@mail.ru*

Abstract. In this paper, an experimental study was conducted to compare the properties of aggregateobtained from destroyed concrete waste, laboratory concrete waste and natural aggregatesused as control samples. The study examines the possibility of using demolition waste to develop building materials with sustainable properties in order to obtain economic benefits from the disposal of man-made waste. Initially, the selection of aggregates from waste was carried out by crushing concrete fragments from demolition waste and laboratory waste, and then studying their physical and chemical properties to obtain fillers and concrete mixtures, make samples, and determine compressive strength. The correlation between the results of various experiments was analyzed and a linear correlation was established between the compressive force and other established mechanical properties. The possibility of recycling construction waste is presented, which leads to the solution of several problems: reducing the cost of processing industrial waste and improving the physical and mechanical properties of concrete due to their introduction as a filler.

Keywords: *concrete destruction waste, laboratory concrete waste, natural aggregates, secondary filler, waste management.*

1. Introduction

One of the most important reserves for saving material and energy resources in the construction industry is the use of waste from precast concrete enterprises and construction objects intended for demolition in the form of concrete scrap [1].

Natural resources are consumed in significant quantities in the construction sector, and a significant amount of construction and demolition waste is produced, which makes up the largest volume of all solid waste.

The abundance of construction waste in different countries has highlighted the importance of countries ' actions to manage, recycle and reuse waste that occurs throughout the life cycle of a particular infrastructure.

The generation of construction waste and the unsustainable use of depleted natural resources for building materials are also associated with the negative impact of the construction industry on the environment. Globally, it is estimated that about 10-30% of landfill waste is generated from construction and demolition work [1].

Environmental goals can be achieved by developing mandatory regulations for the demolition of efficient building materials and the disposal of construction waste, as there is a great need to develop appropriate disposal processes to protect the environment, as well as to obtain economic benefits from waste.

Currently, due to the widespread introduction of complexes for the destruction of substandard reinforced concrete products by mechanical means and the production of crushed stone from crushed concrete, the question of its rational use in the technology of reinforced concrete products and structures arises.

Crushed concrete is characterized by the following quality indicators: grain composition; strength; content of pulverized particles; content of weak grains with a strength of less than 20 MPa; content of lamellar (leshchadny) and needle-shaped grains; frost resistance; abrasion resistance in the shelf drum; content of harmful components and impurities; content of clogging impurities; bulk density (at the request of the consumer).

Crushed stone grains separated from substandard concrete include a cement-sand mortar and a contact zone between them. The presence of this shell, which partially or completely covers the crushed stone grains, is the main difference between secondary aggregate and natural aggregate and leads to an increase in water absorption of the aggregate, respectively, and to a decrease in frost resistance, as well as to an increase in the crushing capacity of the material and weight loss during the abrasion test [1,2].

2. Materials and methods

When forming the structure of cement stone, such aggregate has an impact due to its water demand and water absorption indicators: having increased porosity, crushed stone from crushed concrete will actively absorb water from the concrete mixture, which will lead to insufficient water content in it. Subsequently, when a capillary-porous structure is formed, free water migrates from the pores of the aggregate back to the already hardening cement stone. Therefore, in order to avoid reducing the mobility of the concrete mix when using secondary crushed stone, it is advisable to use superplasticizing additives.

For the production of concrete and reinforced concrete products, as well as in other areas of construction activity, secondary aggregate from concrete scrap must meet the requirements of State Standarts 32495-2013 [2].

For the preparation of the concrete mix, quartz sand (modulus of fineness 2.2) was used as a fine aggregate, and concrete scrap (fraction 5-40 mm) obtained from ordinary concrete and high – strength concrete was used as a coarse aggregate. Portland cement of the M400 brand was used as a binder.

Concrete scrap in the form of destroyed control samples of concrete after testing them for strength determination, made on natural crushed stone and gravel, was accepted for research.

Laboratory samples of secondary aggregate were obtained by crushing concrete scrap in a laboratory jaw crusher.

3. Results and discussion

Table 1. Physical and mechanical characteristics of cement

Portland cement CEM I 42,5 N		
Construction and technical properties of cement		
Indicators	Value	Normalized State Standarts
Specific surface,area, kg/m^2	330	Not normalized
Setting time		
Beginning, h	2.5 h	Not earlier than 2.00
End, h	3.35 h	Not later than 10.00
Compressive strength of cement mortar, MPa in age:		
3 days. -bending -compression	5.8 33.00	Not normalized Not normalized
7 days. -bending -compression	- -	- -
28 day. -bending -compression	8.1 56.6	ne less than 5.9 Not less than 49
Fineness of grinding, residue on the screen 0.008, %	7.00	Not less than 85
Normal density of cement dough, %	25.5	Not rated
The content of sulfur oxide SO_3, %	2.42	Not less than 1.00 Not more than 3.5
The content of chlo-ride ion Cl, %	0.002	Not more than 0.1
C_4AF	13.1	is not normalized rated

Cements were tested in accordance with the requirements of current standards. The cement used fully meets the requirements imposed on it. It should be noted that this cement shows a high compressive strength at the age of 28 days, significantly exceeding the required level.

As a fine aggregate for concrete, quartz sands were used with a fineness modulus M_s=1.01, and a bulk density in the uncompressed state p_h(neup)=1495 kg/m^3, in the compacted state p_y(upl)=1570 kg/m^3, true density p_{ist}=2640 kg/m^3, watervoidness according to STATE STANDARTS 8735-88-43.4%, water demand-5.5%, cement demand-0.530. Sands must meet the requirements of State Standarts 8736-93, the quality of sand is evaluated grain composition, grain size modulus, and chemical composition (Tables 2 and 3).

Table 2. Chemical composition of fine aggregate

Name	Content, mass.					
	SiO_2	Al_2O_3	Fe_2O_3	CaO	R_2O	c.l.
Quartz sand	96.8	0.5	0.9	0.38	0.98	0.44

Table 3. Granulometric composition of fine aggregate

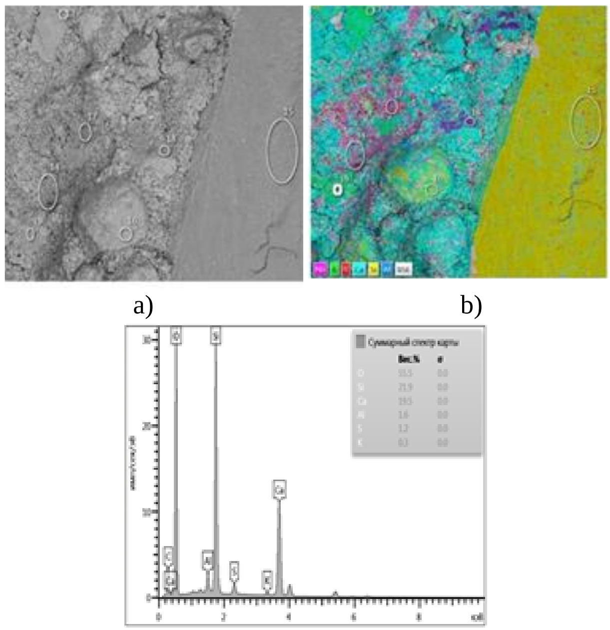
Name	Screen mesh size, mm	2.5	1.25	0.63	0.315	0.16	M_s
Quartz sand	Total residue, %	0.7	1.3	4.6	19.4	75.4	1.01

Course aggregate must meet the requirements of State Standarts 8269.0-97 in terms of strength, bulk volume, grain composition, frost resistance, and total specific effective activity of natural radionuclides. Table 4 shows the chemical composition of concrete scrap from destroyed buildings, which consists SiO_2 (52.5%), CaO (31.4%), Al_2O_3 (6.48%), Fe_2O_3 (4.05%), MgO (1.93%), SO_3 (0.947%), Na_2 (0.927%), K_2O (0.913%). Figure 2 shows the microstructure and chemical composition of concrete scrap, where (a) is a photo of concrete scrap describing the composition and contact zones between cement mortar and coarse aggregate of concrete scrap, (b) is a map of the chemical composition of concrete scrap, (c – is the chemical elements present O (55.5%), Si (21.9%), Ca (19.5%), Al (1.6%), S (1.2%) and K (0.3%) [3.4].

Table 4 shows the granulometric composition of coarse aggregate obtained from concrete scrap, which meets the requirements of State Standarts 8267-93.

Table 4. Chemical composition of concrete scrap

Content, mass. %								
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2	K_2O	c.l.
52.5	31.4	6.48	4.05	1.93	0.947	0.927	0.913	0.853



a) b)

c)

Figure 1. Microstructure and chemical composition of concrete scrap: (a) - a photo of the concrete scrap describing the composition and contact zones between the cement mortar and the coarse aggregate of the concrete scrap, (b) - a map of the chemical composition of the concrete scrap, (c) – the chemical elements present

Table 5. Granulometric composition of concrete scrap fragments (course aggregate)

№	A number of sit	units of measurement	Indicators		
			Private residues	Full residues	Standard value according to State Standarts 8267-93
1	20	%	10	10	up to 10%
2	10		64	74	30-80%
3	5		20	94	90-100%
4	2.5		5	99	95-100%

Table 6. Chemical composition of laboratory concrete waste

Content, mass. %	
SiO_2	91.85
CaO	1.28
Al_2O_3	3.98
Fe_2O_3	0.626
MgO	0.660
Na_2O	0.200
TiO_2	0.623
K_2O	0.673
c.l.	0.108

This study examines case studies from two different sources, the first (C1) – where fragments obtained from concrete cube samples destroyed during testing (laboratory concrete waste) were considered, (Figure 2) and the second (C2) – with fragments of destroyed buildings and structures.

a) b)

Figure 2. Construction waste: a-fragments of destroyed building; b - laboratory concrete waste

As a result of the tests performed, based on a comparison of bulk density, voidness, strength and water absorption indicators for natural and secondary aggregates, we note that the presence of cement mortar on the surface of crushed concrete aggregate, as well as its presence in the [5] form of solid pieces, has a significant effect on water absorption and crushing capacity of secondary material. The test result is shown in Table 7.

Table 7. Determination of grain composition

Naming Indicator name	Calculation result for total balances, %, type of placeholder	
	crushed	
	stone natural	secondary
Granulometric composition,		
total residue on sieves, %:		
40	0	0
20	2	24.5
10	67.8	77.5
5	97.4	98.3
Less than 5	100	100

According to the requirements of State Standarts 32495-2013, the grain composition of the tested natural crushed stone and gravel meets the requirements what for secondary aggregates, there are excess standards on sieves 20 and 40. Such indicators are associated with the presence of cement mortar that did not separate during the crushing of substandard concrete [7].

Table 8. Determination of the filler grade by crushability

Test fraction	Test result, residue on the sieve, % / grade of crushing capacity	
	crushed stone	
	capacity natural	secondary crushed
5-10 mm	8.4 /1000	16.88 / 600
10-20 mm	8.7 / 1000	16.05 / 600

According to the test results, the grade for crushing natural crushed stone and gravel corresponds to 1000, secondary crushed stone-600. Lower indicators of secondary aggregate are explained by the presence of a contact zone between the initial crushed stone grain and the mortar part, which is the weakest link in the concrete structure.

The cement shell remaining on the grains of secondary aggregate has porosity, which leads to an increase in water absorption of such aggregate in comparison with natural aggregate. Also, for this reason, an increase in voidness can be observed. The decrease in the bulk density of secondary aggregate in comparison with natural aggregate is explained by the presence of crushed cement stone and fine aggregate in the test sample.

An experimental study was conducted to compare the properties of aggregate obtained from concrete waste of various origins: fragments of destroyed buildings and structures, laboratory concrete waste, and control aggregate made from natural materials.

In order to study the aggregate properties, a sieve analysis was carried out, and the stability to the decomposition of coarse aggregate, specific gravity, water absorption, bulk density and voidness were determined.

The properties of large secondary and natural aggregate are determined in accordance with State Standarts 8269.0-97 «Crushed stone and gravel from dense rocks and industrial waste for construction work. Methods of physical and mechanical testing" and is evaluated by the technical conditions:

- for natural course aggregate State Standarts 8267-93 «Crushed stone and gravel from dense rocks for construction works. Technical specifications»;
- for secondary course aggregate State Standarts 32495-2013 «Crushed stone, sand and sand-crushed stone mixtures from crushed concrete and reinforced concrete. Technical specifications».

To assess the quality of concrete on secondary aggregate, we used samples-cubes, 100×100×100 mm in size, which were made in metal molds. Compaction of the concrete mixture was carried out by vibrating. Solidification under normal conditions at a temperature of (20±2)C and relative humidity (95±5)%, the tests were performed on day 28.

Concrete properties such as compressive strength on days 3, 7 and 28 and water absorption were determined [7.8].

The experiment was conducted on 3 different concrete compositions. The results oftesting samples for strength, water absorption and porosity are presented in Table 7.

On the basis of aggregates obtained from waste and natural raw materials, laboratory samples of concrete of strength class B35 were made and their compressive strength indicators were determined.

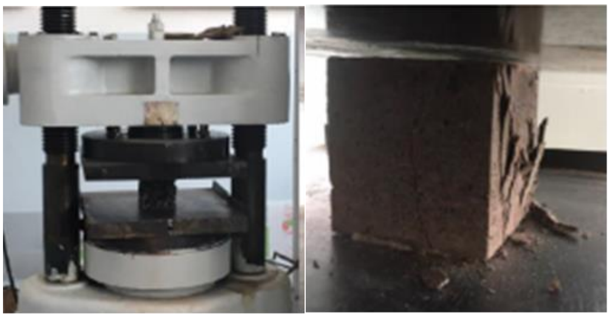


Figure 3. Compression testing of concrete samples

The results obtained show that the bulk density of the tested laboratory concrete waste was higher than in the control sample of natural composition, while the number of voids decreased. This is due to the angularity of the particles, since crushing was used to create a homogeneous aggregate of 15 mm in size.

The results (Table 10) show that the specific gravity increases with decreasing water absorption. The specific gravity of the crushed aggregate is lower than that of the identical traditional aggregate, which is usually about 2.2%-2.5% under saturated dry surface conditions. Due to the cement mortar attached to the particles, the water absorption of the recycled aggregate is much higher than that of a similar primary material, which is usually between 2% and 6 % for coarse aggregate. The results are suitable and fall within an acceptable range.

Possible reason for the high rate of absorption of laboratory-tested concrete waste and concrete waste from destroyed buildings in the higher water-cement ratio used in the mixture. When water evaporates, it leaves voids that take up space in the concrete.

The results show that the compressive strength at the age of 28 days increased with a decrease in the water-cement ratio for all mixtures.

Table 9. Physical properties of crushed stone

Indicators	Natural crushed	Crushed stone from laboratory waste	Crushed stone from demoli-tion waste
Bulk density, (kg/m^3)	1485	1478.3	1245.25
Specific gravity	2.630	2.527	2.520
Water absorption, %	2.3	2.74	11.2
Crushing capacity, %	28	26	35
Grade crushed	stone 600	600	800
Voidness, %	21	39	48.2

Three compositions of concrete samples with aggregate from various sources were produced: fragments of destroyed buildings and structures, laboratory concrete waste from laboratory-tested samples, and traditional aggregate sold on the building materials market, which was used to prepare control samples. All samples were designed with a design compressive strength of 35 MPa. The compressive strength of each sample and the consumption of components for the concrete mixture (Table 8) were determined after 7, 14, and 28 days.

The results show that the control samples exceeded the design strength of 35 MPa. The highest strength is found in samples made from waste samples tested in the laboratory C1, on which the calculated strength was achieved, while samples C2, made from random concrete waste, were slightly lower than the calculated strength.

Table 9. Consumption of components for concrete mix and compressive strength

the composition of concrete	unit of measurement	Control mixture	Waste mixture (C1)	Waste mixture stone (C2)
Cement	kg/ m^3	230	230	230
Crushed stone	stone kg/ m^3	1023	–	-
Sand	kg/ m^3	891	839	814
Crushed stone from waste	kg/ m$^{3\text{-}1075}$	–	1075	1100
Water	l / m^3	180 (45 %)	198 (50 %)	205(51%)
Compressive strength -3 days	MPa	33	28.2	18.3
-7 days	MPa	35.6	28.5	24.1
-28 days	MPa	41.1	34	31

When determining the flexural strength, concrete made with a laboratory-tested concrete waste aggregate, concrete with demolition waste, and traditionally used aggregate were used for comparison.

Three samples of each composition were tested after 7, 14, and 28 days (Table 9). The strength of concrete samples made from traditional aggregate was usually higher than that of samples made from C1 aggregate. In addition, the flexural strength of samples made with C1 concrete waste is also generally slightly higher than that of samples made with C2 aggregate.

The results show that flexural strength increased with increasing compressive strength for the entire mixture.

Figure 4. Determination of flexural strength of concrete samples

When determining the flexural strength, concrete made with a laboratory-tested concrete waste aggregate, concrete with demolition waste, and traditionally used aggregate were used for comparison [8].

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The results show that flexural strength increased with increasing compressive strength for the entire mixture.

Table 10. Average flexural strength (MPa) at different ages

Curing time (days)	Waste mixture (C1)	Waste mixture (C2)	Control mixture
7	2.4	1.9	2.34
14	2.8	2.1	2.91
28	2.9	2.3	3.2

Thus, the possibility of recycling construction waste has been studied, which contributes to solving several problems: cheap waste disposal and increasing the physical and mechanical properties of concrete, due to the introduction of recycled waste as aggregate. Based on the presented material, we can draw the following conclusions:

- thevolume density (specific gravity) of waste for the control sample was higher than for C1, while the number of voids was less.
- thespecific weight of crushed recycled aggregate C2 was lower than that of conventional aggregate, which usually has values from 2.2 to 2.5.
- thewater absorption decrease for the recycled aggregate was much higher than that of conventional aggregate, due to the presence of cement mortar attached to the particles.

When studying the compressive strength, it was found that the control sample has the highest strength, with an average value of 41.1 MPa. The results also show that the average compressive strength of concrete waste C1 has the highest value of 34 MPa, which is very close to the calculated compressive strength of 35 MPa, with an increase in the compressive strength of concrete, there is also an increase in flexural strength [8, 9].

The analysis of the obtained results showed that the compressive strength index is almost identical for the samples of compositions No. 1 and No. 2 with concrete scrap of different strengths. However, the bending strength of samples with aggregate made of ordinary concrete is higher than that of more durable ones. Based on the research results, it was found that the strength of concrete scrap does not significantly affect the strength of concrete. This may be due to the presence of large pores in the samples, since samples with a higher cement content have a higher index of both compressive and flexural strength. Thus, a strong cordon of layers of cement stone with aggregate is the reason for increasing the strength of concrete. The formation of the structure and increase in the strength of concrete is influenced by the fine-pored structure of cement and mortar grains present in the aggregate from concrete scrap.

Samples from a rigid mixture have the highest strength index than samples from a mobile mixture.

The reduced strength of samples with aggregate based on concrete scrap is also due to the fact that the grains of secondary crushed stone contain remaining cement and mortar particles, as a result of mechanical destruction during crushing, their structure becomes more porous and the water absorption of such crushed stone reaches 6-8%. As a result, these factors lead to increased adhesion of the secondary aggregate to other components and compaction of the concrete structure, thereby increasing the adhesion of the cement stone to the aggregate. Therefore, the secondary aggregate has an impact on the structure of both the cement stone and the tight contact zone between the cement stone and the aggregate itself.

According to State Standarts 26633-91 «Heavy and fine-grained concretes. Technical conditions», in terms of compressive strength, samples of concrete on natural and secondary crushed stone correspond to the M300 grade (class B22.5), concrete on natural and secondary gravel – to the M200 grade (class B12.5). The obtained concrete samples correspond to the strength grade specified by the project, which indicates that the composition of the concrete mixture is selected and calculated correctly [10].

In terms of porosity, concrete on natural crushed stone is characterized by a relatively low indicator of the average open pore size and the average value of the open pore uniformity indicator α, which makes the sample have low water absorption. In comparison with it, concrete on secondary crushed stone has an increased indicator , which in practice proves that the secondary aggregate and the cement stone contained on it really increase the water absorption value in the finished concrete.

With a relatively high parameter α and a relatively low parameter, concrete on natural gravel has a lower water absorption compared to concrete on secondary gravel, the average pore size of which is the largest of all the tested compositions. This suggests that the average size of open pores significantly affects the water absorption of concrete. To reduce the water absorption of concrete and increase its frost resistance, it is necessary to use plasticizing and air-entrapping additives.

The results obtained in the experimental part of this paper reflect the possibility of using a secondary coarse aggregate in the production of products and structures with a strength of up to 35 MPa. I found that the secondary fillers are close to the natural ones in their properties. A characteristic difference for aggregates made of crushed concrete is the presence of cement stone grains on the surface, which increases the water absorption of aggregate and finished concrete due to its porosity, and also affects the crushing capacity for the worse. However, their use is advisable in products that allow the use of gravel as a large aggregate. In the samples on the secondary aggregate, a slight decrease in the compressive strength index was observed, which indicates that with the same composition of the concrete mixture, the secondary aggregate does not lead to a decrease in the strength of the finished concrete, but, due to its shortcomings, it cannot be used in products and structures of serious significance.

For the production of secondary aggregate, complexes are used that include two-stage crushing: at the first stage, the products are crushed to the dimensions allowed by the equipment of the second stage and the reinforcement is removed; at the second stage, the crushed pieces are crushed to the required dimensions and divided into fractions using a sorting unit. This approach allows the most efficient separation of coarse aggregate grains from cement stone. The prepared aggregate can then be used for its intended purpose in the production of new reinforced concrete products or in road construction.

It is established that the main physical and mechanical characteristics of secondary aggregate are only slightly inferior to natural aggregate. This is due to the presence of cement on the surface of coarse aggregate grains made of substandard concrete.It is shown that on secondary crushed stone it is possible to obtain concretes of grades 200-300 (classes B12.5–B22.5).

It is established that concretes made on secondary aggregate are slightly inferior to concretes on natural aggregate in terms of water absorption and the size of open pores. To eliminate such shortcomings in the concrete technology, plasticizing and air-entrapping additives should be used.

The main dependences of the properties of aggregates from concrete scrap on their composition and structure are obtained, which are necessary to justify the possibility of their use in concrete of strength classes up to 30 B30 inclusive.

The dependences of the technical properties of concrete mixes on the composition, structure and granulometric composition of aggregates from concrete scrap and the characteristics of the pore space are established.

The dependences of the properties of concrete mixes and concrete on aggregates from concrete scrap are obtained, which are necessary for optimizing the composition of concrete with the required properties.

The influence of concrete scrap aggregate on the cubic strength and water absorption of a sample based on their concrete scrap aggregate is shown.

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Бетон сынықтарын темірбетон бұйымдары үшін үлкен толтырғыш ретінде пайдалану

Ү. Асқарбекқызы*

Satbayev University, Алматы, Қазақстан

**Корреспонденция үшін автор: umkaaskarbekkyzy@mail.ru*

Аңдатпа. Бұл жұмыста сынған бетон қалдықтарынан, зертханалық бетон қалдықтарынан және бақылау үлгілері ретінде пайдаланылған табиғи толтырғыштардан алынған толтырғыштың қасиеттерін салыстыру мақсатында эксперименттік зерттеу жүргізілді. Зерттеу техногендік қалдықтарды кәдеге жаратудан экономикалық пайда алу мақсатында тұрақты қасиеттері бар құрылыс материалдарын жасау үшін бұзу қалдықтарын пайдалану мүмкіндігін зерттейді. Бастапқыда қалдықтардан толтырғыштарды іріктеу бұзу қалдықтары мен зертханалық қалдықтардан бетон қалдықтарын ұсақтау, содан кейін толтырғыштар мен бетон қоспаларын алу үшін олардың физикалық және химиялық қасиеттерін зерттеу, сынамалар жасау, қысу беріктігін анықтау арқылы жүргізілді. Әр түрлі эксперименттердің нәтижелері арасындағы корреляция талданды және қысу күші мен басқа орнатылған механикалық қасиеттер арасындағы сызықтық корреляция анықталды. Құрылыс қалдықтарын кәдеге жарату мүмкіндігі ұсынылған, бұл бірнеше проблемаларды шешуге әкеледі: өнеркәсіптік қалдықтарды қайта өңдеуге кететін шығындарды азайту және оларды толтырғыш ретінде енгізу арқылы бетонның физикалық-механикалық қасиеттерін арттыру.

Негізгі сөздер: *бетонның сыну қалдықтары, зертханалық бетон қалдықтары, табиғи толтырғыштар, қайталама толтырғыш, қалдықтарды жою*.

Использование бетонного лома в качестве крупного заполнителя для железобетонных изделий

У. Аскарбеккызы*

Satbayev University, Алматы, Казахстан
**Автор для корреспонденции: umkaaskarbekkyzy@mail.ru*

Аннотация. В данной работе проведено экспериментальное исследование с целью сравнения свойств заполнителя, полученного из разрушенных отходов бетона, лабораторных отходов бетона и природных заполнителей, использованных в качестве контрольных образцов. В ходе исследования исследуется возможность использования отходов сноса для разработки строительных материалов с устойчивыми свойствами с целью получения экономической выгоды от утилизации техногенных отходов. Первоначально отбор заполнителей из отходов производился путем дробления обломков бетона из отходов сноса и лабораторных отходов, а затем изучения их физических и химических свойств для получения наполнителей и бетонных смесей, изготовления проб, определения прочности на сжатие. Была проанализирована корреляция между результатами различных экспериментов и установлена линейная корреляция между силой сжатия и другими установленными механическими свойствами. Представлена возможность утилизации строительных отходов, что приводит к решению нескольких проблем: снижению затрат на переработку промышленных отходов и повышению физико-механических свойств бетона за счет внедрения их в качестве наполнителя.

Ключевые слова: *отходы разрушения бетона, лабораторные отходы бетона, природные заполнители, вторичный заполнитель, утилизация отходов*.

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