Study of physical-mechanical properties of concretes based on recycled aggregates

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Abstract. The use of hybrid alkaline cements is effective for materials of general construction and special purpose, namely in the production of concrete mixtures and concretes based on them with an increased risk of structural loosening due to an increased content of organic residues and combustion products. Materials based on them are able to withstand the significant impact of swelling-shrinking deformations caused by the presence of combustion products and organic residues. This makes it possible to predict the effectiveness of their introduction to control the processes of concrete structure formation based on recycled aggregates.

It is shown that the use of recycled aggregate in the composition of a concrete mixture based on alkaline cements makes it possible to obtain concrete mixtures of different mobility and concretes based on them, which according to their physical and mechanical properties meet the requirements for concrete for general construction purposes. Thus, recipes for concrete with an average density of 2200...2420 were developed kg/m3 and compressive strength at the age of 28 days at the level of 15.1...39.8 MPa at mobility of concrete mixture P2.

The strength at the initial and middle terms of hardening (2 days and 7 days) also corresponds to the generally accepted indicators of the set strength of concrete of different classes.

At the same time, the water-cement ratio of the studied concretes is characterized by sufficiently high indicators and varies at the level of 0.5...0.8, which is often unacceptable according to regulatory

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documents for concretes for general construction purposes, potentially creating problems with the long-term properties and durability of such concretes.

Solving the mentioned problems is possible due to the selection of the composition of concrete mixtures by modifying them with additives of different origin and functionality.

Keywords: concrete, recycling, demolition waste, cement, exploitation properties, aggregates.

INTRODUCTION

The war started by Russia had devastating consequences on the infrastructure of Ukraine, creating an acute problem of disposal of a huge amount of construction waste. According to preliminary estimates, the volume of such waste already reaches several million tons and continues to grow. Natural landfills with hazardous materials such as asbestos pose a serious threat to the environment and human health, as they cause groundwater and air pollution and worsen the sanitary-epidemiological situation.

Modern technologies make it possible to turn construction waste into full-fledged construction materials. Crushed concrete fragments can successfully replace natural aggregates or even become part of cement. This significantly reduces the pressure on the environment, reducing the need to extract new materials and reducing the amount of waste sent to landfills, as well as making construction more cost-effective and contributing to the development of the construction industry. Thus, the production of aggregates from concrete waste allows you to create a closed cycle in the construction industry and reduce the consumption of natural resources. However, the surface of secondary concrete aggregates has a porous structure with cement residues, which negatively affects their adhesion to the cement paste in new concrete. This leads to a decrease in the strength and durability of structures. To improve the properties of secondary concrete aggregates, it is suggested to treat their surface with special additives. The use of pozzolanic additives and superplasticizers will make it possible to seal the surface of the aggregate and increase the strength of the connection with the cement paste.

This direction of research is aimed at the development of scientific foundations for the use of construction debris, which was formed as a result of destruction, as a secondary raw material for construction. Using modern methods of analysis, it is possible to assess the potential of various types of waste and develop recommendations for their effective use in construction, which will allow creating safe and energy-efficient houses and structures.

The question of application of mentioned-above aggregate a little bit complicated due to the problems in joint work of such aggregates with cementitious system. In various studies had been shown that the most effective cements for this case could be alkali activated cements, developed by scientific school SRIBM named after prof. Glukhovskii. Advantages of such materials had been underlined in the paper of different scientists all over the world.

Preliminary study had shown possibility to make mix design of concretes for common application using alkali activated cements and non-conditional aggregates, including recycled aggregates form demolition wastes.

PURPOSE OF THE STUDY

The purpose of the present study was to provide preliminary mix design of the concrete mixes using slag alkali activated cement and recycled aggregates.

The aim of the study was to determine possibility to obtain concretes for common use based on recycled aggregates form demolition wastes, to test their service properties and to underline the problems in the concrete structure formation have to solve during the future investigations.

MATERIALS AND TEST METHODS

As the main aluminosilicate component for slag alkali activated cement, granulated blast furnace slag (Kryvyi Rih, Ukraine) was used, according to DSTU B.V.2.7-302:2014, ground to a specific surface area of S=450 m^2/kg by Blain and the modulus of basicity M_o=1.11. Sodium metasilicate pentahydrate ($Na_2SiO_3 \cdot 5H_2O$) and soda ash (Na_2CO_3) were

used as an alkaline component. The alkaline component was used in a dry, powdery state.

Dnieper sand with M_k=1.2 was used as fine aggregate for slag-alkaline concrete (DSTU B V.2.7.-32-95).

In the control concrete composition was used granite coarse aggregated with the fraction 5-20 mm (35 % of 5-10 mm fraction and 65 % of 10-20 mm fraction).

To investigate the possibility of creating effective slag-alkaline concrete based on materials from recycled destroyed concrete structures, recycled aggregate with a heterogeneous grain composition (Table 1.) was used, from which crushed stone fraction 5-20 was separated.

Physical-mechanical characteristics of crushed stone from recycled concrete structures, such as grain composition, the content of grains with weak pores, the content of dusty and clay impurities, the content of laminar (planar) and needle-shaped grains, crushing, frost resistance, water absorption was determined according to DSTU 9179:2022.

Table 1. Grain composition of recycled aggregate

Sieve No	Rest on the sieve, %
20	18.34
10	19.16
5	12.5
2.5	7.54
1.25	5.28
0.5	8.7
0.25	15.87
0.16	6.26
0.05	5.67
≤ 0.05	0.68

Content of poor particles in the composition of artificial aggregate is 18% by mass, not meeting the requirements of the standard DSTU B V.2.7-75-98 (have to be less than 15 for the aggregate with a crushing capacity of 300).

The content of dusty and clay admixtures for the 5-20 mm fraction is 3.7% (according to DSTU B V.2.7-75-98, up to 3% is permissible for grades with a crushing capacity of 200, 300, 400).

The content of lamellar (sparing) and needle-shaped grains - 24% (improved group (from 15 to 25%) in accordance with DSTU B V.2.7-74-98).

The pH value of pore solution in the artificial aggregate is 7 (neutral). It is suitable to be applicated as an artificial aggregate to obtain new concrete mixes and concretes on their basis.

Water absorption of recycled aggregates is 10.5 % by mass of the aggregate.

Frost resistance of the recycled aggregate is F15 (according to DSTU B V.2.7-47-96, for 15 cycles of frost resistance the loss of sample mass after testing is up to 10%, in our recirculated one - 13.5% by mass). That means that artificial aggregates are also not meeting the requirement of standard and cannot be used for the concrete for common application in the aim to obtain normal exploitation properties of the concrete constructions. Concrete on the basis of such aggregates have to be checked experimentally

Frost resistance of concrete (DSTU B B.2.7-47-96) was determined by the accelerated method. The criterion for evaluating the frost resistance of the concrete specimen are the sample mass loss in %, loss of compressive strength and loss of surface.

Physical-mechanical properties of concrete were tested according to the DSTU B V.2.7-224:2009 demands.

RESULTS AND EXPLANATIONS

At the first stage of the study were investigated properties of the concrete on traditional granite aggregates. Properties of such concretes were compared with properties of concretes on recycled aggregates form demolition waste basis.

Compositions of the concrete mixes and concretes on their basis are shown in Table 2.

Properties of concretes under study are given in Table 3.

As it seems from the Table 2, compositions on the granite aggregate basis are characterized by water to cement ratio 0.5. At the same time, compositions on the recycled aggregates bases are characterized by much higher W/C ratio (from 0.56 to 0.8). Such difference could be

explained by high porosity of aggregates so as by high content of powder-like fractions. Potentially this will lead to the lower service properties, especially initial compressive and flexural strength and 28 days strength, so as frost resistance.

Table 2. Composition of concretes on alkali activated cement and recycled aggregates basis

Marking	Aggregates type	Composition, kg					W/C	Slump, cm
		MC	Soda ash	Slag	Aggregate	Sand		
1K4/6	Granite, fr 5-20	13,2	19,8	297	1180	780	0,5	8
1K5/8	Granite, fr 5-20	26,4	16,5	287,1	1180	780	0,5	8
1P	Recycled, not classified	26,4	16,5	287,1	1180	780	0,83	9
1PC	Recycled, without poor fraction	26,4	16,5	287,1	1180	780	0,8	10
1P5-20	Recycled, fr. 5-20	26,4	16,5	287,1	1180	780	0,63	8
1PM	Recycled, washed fr. 5-20	26,4	16,5	287,1	1180	780	0,56	8
2PM	Recycled, washed fr. 5-20	26,4	16,5	287,1	1230	750	0,56	9
3PM	Recycled, washed fr. 5-20	26,4	16,5	287,1	1130	830	0,56	9

Table 3. Service properties of concretes under study

Marking	Compressive strength, MPa			Mean density, kg/m^3
	Thermal curing	7 days	28 days	
1K4/6	23.7	19.0	34.5	2420
1K5/8	23.0	21.0	39.8	2430
1P	6.3	5.7	15.1	2180
1PC	7.0	6.5	16.3	2210
1P5-20	10.2	9.4	19.6	2310
1PM	16.8	15.0	25.0	2350
2PM	13.9	12.6	25.7	2360
3PM	12.0	11.4	32.0	2280

Analysis of the given results shows that system needs higher alkaline content to obtain good results. Thus, composition 1K4/6 with lower content of alkalis in the case of using granite aggregates showed not bad strength properties – 35.9 MPa at 28 days age, however, increasing of alkalis content leads to significant increasing in strength properties to 39.8 MPs. In that case, all other compositions were done using high alkaline content.

As is shown at Figure 1, use of recycled aggregate results in strength drops of the concretes nevertheless of specimens' pretreatment type. Concrete mix based on aggregates without any pretreatment is characterized by 0.83 water to cement ratio and thus compressive strength of the system is also low – 15.1.

One of the possible reasons of strength drops could be presence of poor fractions in aggregates. As it shown, this is true, after separation and extraction of poor fractions strength a little bit increased, but only to 16,3 MPa. That means that a main problem in our case is not s poor fraction presence.

In case of additionally washing pretreatment of aggregates and drying after that compressive strength rises to 25 MPa, that is not bad, but much lower comparing to the systems on granite aggregate.

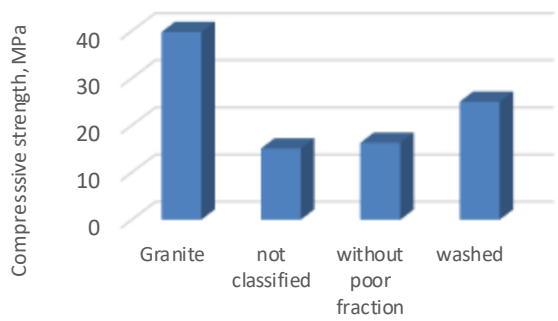

Figure 1. Compressive strength of the concretes under study depending from the aggregate type

Given results had proof that one of the main problems in using of recycled aggregated from the demolition wastes origin is the presence of fine, powder-like particles, which needs a lot of wastes to be sprayed and that results on final strength of the system.

So, for the next investigations were used concrete mixes based on classified and additionally washed artificial aggregates from the demolition wastes.

The next step was to study influence of ratio between coarse/fine aggregates in the system in the aim to additionally reduce the number of powder-like fractions and also to reduce defectiveness of the concrete system due to the presence of the particles with pores, cracks and other defects, as it was shown in the previous studies.

Study was conducted using alkali activated slag cement in the quantity 330 kg/m^3 and mentioned above aggregates. We try to increase or reduce content of recycled aggregates in the aim to find out optimal content. Results of the study are shown on Figure 2.

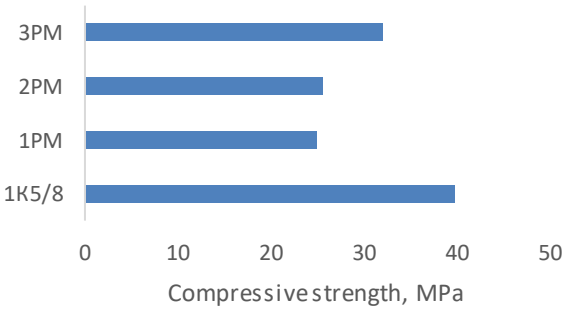

Figure 2. Compressive strength of the concretes on alkali activated cement depending from the mix of aggregates

As it seems from the results all the compositions have a similar water to cement ratio. That means that powder particles are really washed out and thus not influenced on the concrete mix properties, so as on concrete characteristics. In general, concretes on recycled aggregates are showing almost equal strength characteristics for basic 1180 kg of aggregate content and increased 1230 kg content – about 25 MPa, by at the same time reduction of the aggregate content to 1130 kg leads to the strength gain up to the 32 MPa.

At present stage of the studies strength of concrete on the recycled aggregates basis is still lower than properties of control composition on granite aggregate basis, but there were find some regularities which will be useful for the further optimization of concrete mix design.

CONCLUSIONS

The use of hybrid alkaline cements is effective for materials of general construction and special purpose, namely in the production of concrete mixtures and concretes based on them with an increased risk of structural loosening due to an increased content of organic residues and combustion products. Materials based on them are able to withstand the significant impact of swelling-shrinking deformations caused by the presence of combustion products and organic residues. This makes it possible to predict the effectiveness of their introduction to control the processes of concrete structure formation based on recycled aggregates.

The design of the composition of concrete mixtures based on recycled aggregates faces the problems of high water sorption by aggregates even with careful preliminary processing and classification of secondary aggregates - sieving, additional separation and selection of grains of weak rocks, washing, etc. However, this does not allow solving the problem of the presence of microcracks and porosity of the artificial aggregate structure based on recycled concrete structures.

It is shown that the use of recycled aggregate in the composition of a concrete

mixture based on alkaline cements makes it possible to obtain concrete mixtures of different mobility and concretes based on them, which according to their physical and mechanical properties meet the requirements for concrete for general construction purposes. Thus, recipes for concrete with an average density of 2200...2420 were developed kg/m3 and compressive strength at the age of 28 days at the level of 15.1...39.8 MPa at mobility of concrete mixture P2.

The strength at the initial and middle terms of hardening (2 days and 7 days) also corresponds to the generally accepted indicators of the set strength of concrete of different brands.

At the same time, the water-cement ratio of the studied concretes is characterized by sufficiently high indicators and varies at the level of 0.5...0.8, which is often unacceptable according to regulatory documents for concretes for general construction purposes, potentially creating problems with the long-term properties and durability of such concretes.

Solving the mentioned problems is possible due to a more in-depth study of the selection of the recipe composition of concrete mixtures by modifying them with additives of various origin and functionality, causing a decrease in the overall porosity of the system, plasticization and a decrease in water consumption of the concrete mixture, the use of additives that provoke self-healing of the concrete structure and compaction.

In addition, the question of the presence in the structure of such a secondary aggregate of the remains of organic compounds, unburned carbon particles, wood and other pollutants, which are typical for waste from the destruction of reinforced concrete structures, formed as a result of hostilities, requires additional research.

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Дослідження фізико-механічних властивостей бетонів на основі рециркульованого заповнювача

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Анотація. Використання гібридних лужних цементів є ефективним для матеріалів загально будівельного та спеціального призначення, а саме при виготовленні бетонних сумішей та бетонів на їх основі з підвищеним ризиком розхитування структури внаслідок підвищеного вмісту органічних залишків та продуктів горіння. Матеріали на їх основі здатні витримувати значний вплив деформацій набухання-усадки, що обумовлюються наявністю продуктів горіння та залишків органіки. Це дозволяє прогнозувати ефективність їх запровадження для управління процесами структуроутворення бетонів на

основі рециркульованих заповнювачів.

Проєктування складу бетонних сумішей на основі рециркульованих заповнювачів зіштовхується із проблемами високої сорбції води заповнювачами навіть за умови ретельної попередньої обробки і класифікації вторинних заповнювачів – просіювання, додаткова сепарація та відбір зерен слабких порід, промивання, тощо. Проте це не дозволяє вирішити проблему наявності мікротріщин та пористості структури штучного заповнювача на основі рециркульованих бетонних конструкцій.

Показано, що використання рециркульованого заповнювача у складі бетонної суміші на основі лужних цементів дозволяє отримувати бетонні суміші різної рухливості та бетони на їх основі, що за своїми фізико-механічними властивостями відповідають вимогам до бетонів загальнобудівельного призначення Так, було розроблено рецептури бетонів середньою густиною 2200…2420 кг/м3 та міцністю при стиску у віці 28 днів на рівні 15,1…39,8 МПа при рухливості бетонної суміші Р2.

Міцність на початкових та середніх термінах тверднення (2 дні та 7 днів) також відповідає загальноприйнятим показникам набору міцності бетонів різних марок.

Водночас, водоцементне відношення досліджуваних бетонів характеризується достатньо високими показниками і варіюється на рівні 0,5…0,8, що часто є неприйнятним згідно нормативних документів для бетонів загальнобудівельного призначення, потенційно закладаючи проблеми з тривалими властивостями і довговічністю таких бетонів.

Вирішення зазначених проблем можливо за рахунок більш глибокого пропрацювання підбору рецептурного складу бетонних сумішей шляхом модифікації їх добавками різного походження та функціоналу, обумовлюючи зниження загальної пористості системи, пластифікацію і зниження водопотреби бетонної суміші, використання добавок, що провокують замозаліковування структури бетону і компактування.

Крім того, додаткового дослідження потребують питання наявності у структурі такого вторинного заповнювача залишків органічних сполук, невипалених вуглецевих частинок, деревини та інших забруднювачів, що характерні саме для відходів руйнування залізобетонних конструкцій, що утворились внаслідок ведення бойових дій.

Ключові слова: бетон, рециркуляція, відходи руйнувань, експлуатаційні властивості, заповнювачі.