Characterization of recycled aggregates to obtain concretes for common application

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Abstract. The article is devoted to the study of possibility to use demolition wastes as an aggregate to create new effective concrete constructions.

It had been shown that artificial aggregates from demolition wastes, especially from military origin, are very various and complicated in their composition.

All demolition wastes are characterized by weak and damage structure. There are a lot of damages and cracks are present in the aggregates, lowering their service properties and properties of concretes on their basis. Moreover, such aggregates appeared from the war reasons also are containing a lot of additional problems such as rests of organic compounds, unburned particles form the fire and explosion, etc.

It was shown that such kind of demolition wastes contain a lot of fine particles, influencing in a bad way on water consumption of the concrete mix. Also powder-like particles influence bad on service properties of concrete as well as on water to cement ratio in the concrete mix.

However, it was proved that beside of negative influence of aggregates from demolition wastes on concrete properties, it is still possible to obtain concrete mixes and concretes on their bases able to be used as a common concrete.

The best results are obtained using slag alkali activated cement. Compressive strength up to 32 MPa at 28 days is comparable to compressive strength of the control composition using OPC and traditional granite aggregate – 34 MPa at the age of 28 days of normal hardening. Use of slag OPC and recycled aggregates leads to the low compressive strength – up to 24 MPa at the age of 28 days.

Also, it should be mentioned that all concretes under study were characterized by low flexural strength, proving necessarity to provide further mix design to increase strength properties of concrete on

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recycled aggregates basis.

Keywords: concrete, recycling, demolition waste, cement, characterization, aggregates.

INTRODUCTION

The priority and relevance of the given direction of research is determined by the need to dispose of a huge layer of products of human life - waste, which is formed during the destruction of concrete and reinforced concrete structures and buildings. It is known that materials based on port-land cement systems are irreversible products that are not subject to chemical decomposition and can be disposed of only by mechanical processing [1]. In world practice, more and more works of scientists are appearing aimed at solving this problem [2]. At the same time, the use of similar materials also leads to the appearance of defects that are not inherent in traditional concrete structures [3,4]. First of all, the issue is due to the increased defectiveness of the material structure of the recycled aggregate itself, which in the process of processing and classification acquires structural defects (microcracks) and, accordingly, deteriorates the properties of the final product.

For Ukraine, the issue of using such materials is even more acute, since according to the statistics of the confederation of builders of Ukraine and the Ministry of Infrastructure Reconstruction and Regional Development, more than 100 million m^2 of housing stock are damaged and destroyed today, not counting industrial buildings and infrastructure facilities. Most of such structures are subject to dismantling and disposal, which causes the creation of huge depositories on the lands of the agricultural and industrial fund. In addition, just to restore the lost fund of buildings and structures, a huge amount of building materials will be needed, and already today the Union of Building Materials Manufacturers predicts terrible shortages of building materials in all positions. Accordingly, the solution to the problem should be the use of processing products of destroyed structures as raw materials for the manufacture of new ones [5-6]. Also, in the conditions of large-scale restoration, a significant shortage of cement is expected (optimistic forecast of the production of traditional cement up to 20 million tons with a projected demand of 30 million tons/year), which can be partially filled by due to the use of alkaline cements, for which there is a full regulatory framework in Ukraine.

The issue of using materials based on recycled aggregates and alkaline cements is actively researched in the world scientific market [7-8], studying the behavior of such materials in various operating conditions [9-10]. Researchers note the perspective of using such systems and high operational indicators, at the same time noting the increased cost of such technologies and the complexity of the technology of obtaining the material compared to traditional cement systems. At the same time, the Ukrainian school of alkaline cements, which is the progenitor of such materials and has more than 65 years of experience in the development of materials based on them, is significantly ahead of its global counterparts in terms of the development of resource-efficient and economical materials, offering relatively cheap and technological methods of organizing production in the shortest possible time.

Representatives of the scientific school of the NDIVM named after V.D. Glukhovsky were engaged in the study of issues of directed structuring of cements and concretes for various purposes within the framework of research topics, state budget and farm contract developments, as well as international projects (INTAS, COST Action, etc.), in particular, they studied the issues of differences in the structuring of materials based on traditional and alkaline cements.

Artificial stone based on alkaline binders, unlike other cement systems, is characterized by high structural stability and durability under the influence of factors that cause "shaking" of the structure, which is associated with a reduced basicity of the phase composition of hydrate neoplasms and its difference from traditional systems. The issue of directed control of cement and concrete structuring processes was widely studied by the scientific school, in particular in the works of SRIBM KNUCA school., and related in particular to the study of the processes of directed formation of the structure of materials of various purposes based on man-made raw materials.

The results of the research confirmed the effectiveness of the scientific approaches of the SRIBM, at the same time, the issue of directed management of the processes of structure formation of alkaline cements in order to obtain a low-defect structure of materials based on recycled aggregates requires further work that is innovative for domestic and world science.

PURPOSE OF THE STUDY

The analysis of literary sources shows that obtaining concrete mixes and concretes based on recycled building structures is a quite possible issue, however, there are additional challenges to the design of the composition imposed by the military nature of the generation of such waste and, accordingly, the crushed stone imposes very specific requirements.

The purpose of the present study was to provide characterization of the demolition wastes and coarse aggregates on their basis and also to investigate the potential possibility of obtaining concrete based on recycled building (concrete) structures using slag-alkaline cement of the LCEM-I type, as well as to study the physical and mechanical properties of the materials obtained.

MATERIALS AND TEST METHODS

As the main aluminosilicate component for slag-alkaline 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).

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

The frost resistance of crushed stone (DSTU 9179:2022, DSTU B B.2.7-75-98) was determined by the accelerated method by alternating vitrification for 4 years in a sodium sulfate solution and drying it in a drying chamber (temperature 105±5ºC) for the next 4 years. The criterion for evaluating the frost resistance of the aggregate is the sample mass loss in %, depending on the size of the fraction and all test cycles.

Determination of the defectiveness of the structure of coarse aggregate was carried out by the method of electron microscopy with the help of an electronic digital microscope Digital Microscope.

The consistency of concrete mixtures was evaluated by the values of slump (OK) in accordance with DSTU B V.2.7-114-2002. Determination of the compressive strength of concrete was carried out on cube samples with an edge size of 10 cm according to DSTU B V.2.7-223:2009. The samples were hardened under normal conditions (20±2ºC and relative humidity of 95±5%). 7 and 28 days were taken as the reference terms for determining the strength, after preliminary studies the classification of slag alkali activated cement used in the production of control compositions of the M400 concrete mix (45.3 MPa for 28 days of hardening) was established.

RESULTS AND EXPLANATIONS

As it was shown before, composition of artificial aggregate is very complicated. There are a lot of different fractions, normally not or almost not present in the aggregate composition.

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. It means the water absorption of such aggregates is much higher than the one for traditional granite aggregate (less than 2 % by mass). Potentially it has to lead to high water consumption of the concrete mixes on their basis and thus to the reduced properties of concretes.

Frost resistance of the recycled aggregate is F15 (according to DSTU B V.2.7-75-98, 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.

Such lowered characteristics of artificial aggregates are the function of weak structure of recycled aggregate. As a result of destruction of concrete structures, especially because of war influence, these recycled aggregates are characterized by different defects in the structure of aggregate themselves, first of all, resulted in cracks appearance. Results of the study of artificial aggregate structure by micro photo analysis is shown on Figure 1.

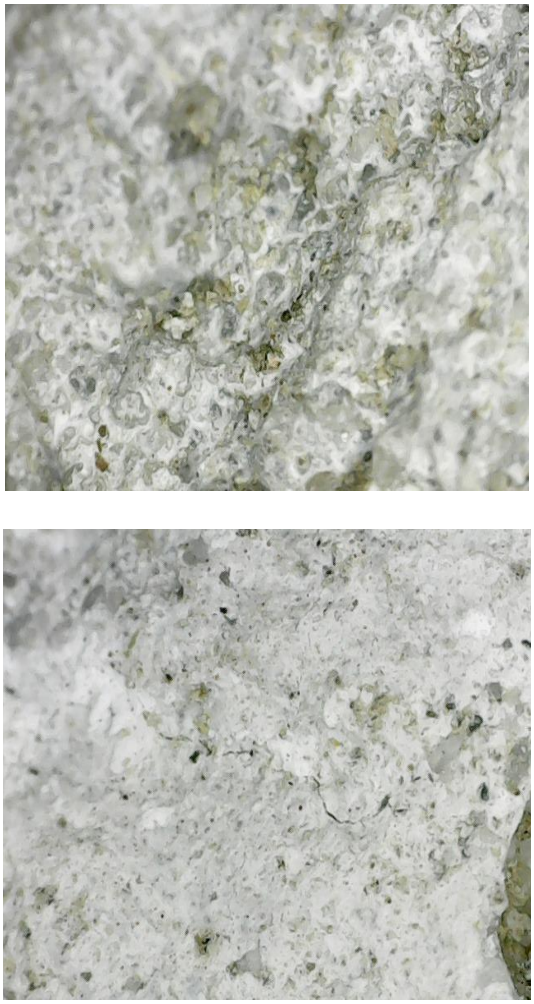

Figure 1. Structure of recycled aggregates at 500 times magnification. Microcracks on the surface of aggregate

Moreover, cracks are not all defects of the structure of artificial aggregates from demolition waste. There are a lot of ithers structure defects, first of all, pores with different origin. It could be pores from the former concrete structure of new-appeared pores because of destruction of concrete and lost or nature aggregates on their position in the structure. Different examples of such pores are shown on Figure 2.

Dimension of such pores and voids could be from 0.5 to 1 mm, lowering properties of aggregate structure and in combination with cracks leads to the low service properties of concrete on recycled aggregates basis, mostly influencing negative on flexural strength of the concrete.

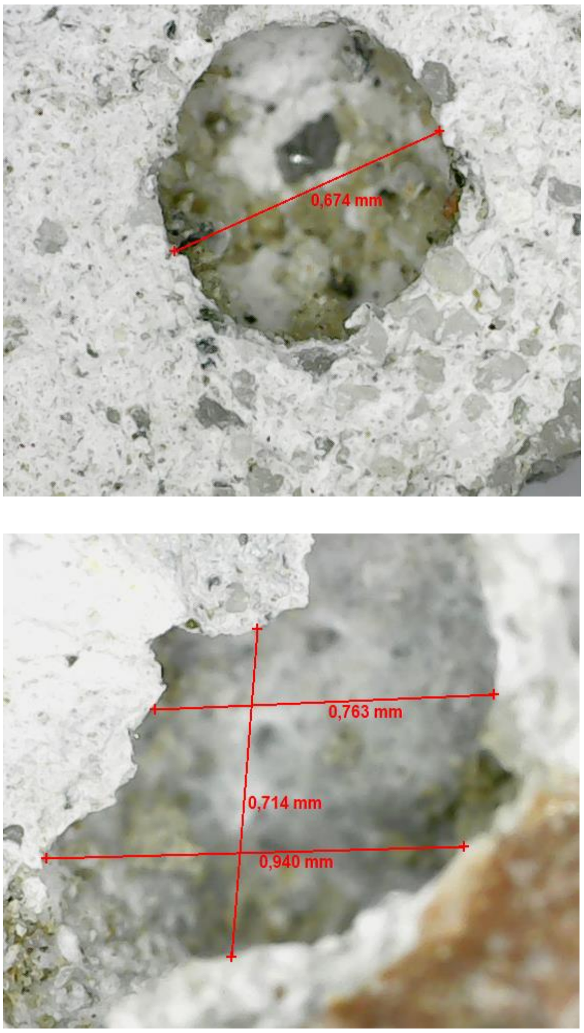

Figure 2. Structure of recycled aggregates at 500 times magnification. Pore on the surface of aggregate

As it seems from the concrete structure, beside of dense structure of the body of artificial aggregate, cracks, holes and pores are weaking the structure of recycled aggregate, making them bad choice for providing concrete mix design. Use of such aggregates leads to the increased loses of cementitious and mortar component so far as higher water consumption of the concrete mix. Also, according to the standard, concrete mix recipe has to be verified by practical application of the mix.

To determine principal possibility to use recycled aggregates for concrete mix design a raw of the experiments had been done using different proportion of components and different cements (represented by traditional OPC, slag OPC and alkali activated cement Type LCEM-I according to the DSTU B V.2.7-181.

Mix design and composition of preliminary concrete mixes on alkali activated cement basis are given in Table 2. All the concrete mixes are present with P2…P3 grade according to the flowability.

As it seems from the given results, the best properties for the compositions with equal cement content (330 kg/m^3) are shown by the mixes with lower coarse aggregate content and a little bit increased fine aggregate content. It could be explained by the shorten of powder-like particles because of reducing recycled aggregate content, resulting in higher slump because of lower water consumptions of the powders.

Increasing of the cement content together with reducing of coarse aggregates content leads to the rising of slump because of the already discussed reasons, and also to the rising of compressive strength – up to 32 MPa at 28 days of normal hardening for the system with 370 kg of the cement comparing to 27 MPa for the system with 330 kg/m^3 of cement content. By the way, the compressive strength of traditional concrete on OPC and granite aggregate basis is 34 MPa, closed to the obtained results, but with increased alkali activated cement content.

Also, it has to be mentioned that flexural strength of all the compositions under study is low. The shown regularity witnesses that flexural strength is about equal for the compositions with 330 and 370 kg of cement (compressive strength, as it was mentioned) is significantly higher. As for the equal cement content, flexural strength is higher for the compositions with higher content of coarse aggregate. This could be explained by the increased content of needle-like particles. However, flexural strength of the OPC based concrete using granite aggregates is much higher – over 7 MPa. Thus, further studies had to be done to increase flexural strength of concretes under investigations.

Mix design and composition of preliminary concrete mixes on different cements basis are given in Table 3. All the concrete mixes are characterized with the slump 9-11 cm. Cement content was also equal – 330 kg/m^3.

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

No	Composition			Slump	Compressive strength, MPa			Flexural strength, MPa		
	Cement	Coarse aggregate Fr.5-10	Sand		1 day	7 days	28 days	1 day	7 days	28 days
1	330	1180	780	10	7	13	27	0.3	1.2	2.7
2	330	1230	750	8	5	11	24	0.2	1.1	2.7
3	330	1130	830	12	7	12	28	0.4	1.0	2.4
4	350	1180	760	12	10	15	28	0.6	0.9	2.6
5	370	1180	780	13	12	16	32	0.9	1.2	2.7

Table 3. Composition of concretes on different cements and recycled aggregates basis

No	Cement type	Composition			Slump	Compressive strength, MPa			Flexural strength, MPa		
		Cement	Coarse aggregate Fr.5-10	Sand		1 day	7 days	28 days	1 day	7 days	28 days
1	OPC	330	1180	780	10	7	13	27	0.3	1.2	2.7
2	Slag OPC	330	1180	780	9	3	12	24	-	0.6	2.2
3	LCEM	330	1180	780	11	8	22	32	0.4	1.5	3.2

Use of different cements results in different hardening speed and thus different initial and normal strength. After 1 days of hardening slag OPC based concretes were shown were low compressive strength and showing no flexural one at all. Concretes on alkali activated cement and OPC basis were very closed in service properties at this age with a little advantage of alkali activated cement.

At the age of 7 days slag OPC is showing high strength gain and almost reaches the strength of OPC based concrete (12 MPa against 13 MPa). Alkali activated cement-based concrete at that stage of hardening rises its compressive strength up to 22 MPa and flexural strength 1.5 MPa, becoming the best choice.

At the age of 28 days OPC-based concrete rises the compressive strength and shortening the difference with the alkali activated cement-based concrete (27 MPa Vs 32 MPa), but still far from it in flexural strength (2.7 MPa versus 3.2 MPa). The worst result for the compressive and flexural strength both had concrete on slag OPC bases.

CONCLUSIONS

As a general result of the study, it could be noted that artificial aggregates from demolition wastes, especially from military origin, are very various and complicated in their composition.

All demolition wastes are characterized by weak and damage structure. There are a lot of damages and cracks are present in the aggregates, lowering their service properties and properties of concretes on their basis. Moreover, such aggregates appeared from the war reasons also are containing a lot of additional problems such as rests of organic compounds, unburned particles form the fire and explosion, etc.

It was shown that such kind of demolition wastes contain a lot of fine particles, influencing in a negative way on water consumption of the concrete mix. Also powder-like particles influence bad on service properties of concrete as well as on water to cement ratio in the concrete mix.

However, it was proved that beside of negative influence of aggregates from demolition wastes on concrete properties, it is still possible to obtain concrete mixes and concretes on their bases able to be used as a common concrete.

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Flexural strength of all the compositions under study is very low (up to 3.2 MPa comparing to the 7 MPa for the control concrete composition).

That is proving necessarity to provide further mix design to increase strength properties of concrete on recycled aggregates basis.

In the following studies the main attention has to be paid to the increasing a service property of concretes as in compressive, so as in flexural strength. Probably, it could be done by modifying of the concrete mixes by admixtures with various origin.

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Вивчення характеристик рециркульованого заповнювача для виготовлення бетонів загальнобудівельного призначення

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Анотація. Стаття присвячена дослідженню можливості використання відходів руйнувань будівельних конструкцій як заповнювача для створення нових ефективних бетонних конструкцій.

Показано, що штучні заповнювачі з відходів руйнування, особливо військового походження, дуже різноманітні та складні за своїм складом.

Всі відходи руйнувань залізобетонних конструкцій характеризуються слабкою і пошкодженою структурою. У заповнювачах на їх основі багато пошкоджень і тріщин, що знижує їх експлуатаційні властивості та властивості бетонів на їх основі. Крім того, такі заповнювачі, що утворились як наслідок ведення бойових дій, також містять багато додаткових проблем, таких як залишки органічних сполук, незгорілі частинки від пожежі та вибуху, залишки пластику та дерев'яних конструкцій, потенційно залишки вибухових речовин, тощо. Наявність усього вищенаведеного значно ускладнює питання використання відходів зруйнованих будівель для виготовлення бетонів, а також ніколи не

досліджувалось закордонними дослідниками з огляду на відсутність в них досвіду роботи із матеріалами, що утворились внаслідок ведення бойових дій.

В результаті проведення детальної характеризації заповнювача теоретичної фракційності 5-20 мм на основі зруйнованих бетонних конструкцій показано, що такі відходи руйнування містять багато дрібних часток, які негативно впливають на водоспоживання бетонної суміші. Також порошкоподібні частинки, які присутні у системі у достатньо великому обсязі і являють собою не тільки залишки бетонних конструкцій, але й глинисті компоненти зі складу ґрунтів, негативно впливають на експлуатаційні властивості як бетонної суміші, так і бетону на її основі, а також на співвідношення води і цементу в бетонній суміші.

Проте доведено, що незважаючи на негативний вплив заповнювачів з відходів руйнування на властивості бетону, все ж можна отримати бетонні суміші та бетони на їх основі, які можна використовувати як бетони загальнобудівельного призначення.

Найкращі результати дає використання лужного цементу. Міцність при стиску до 32 МПа у віці 28 діб співставна із міцністю при стиску контрольного складу з використанням портландцементу і традиційного гранітного заповнювача – 34 МПа на 28 добу нормального тверднення. Використання як цементу шлакопортландцементу і рециркульованих заповнювачів призводить до низьких показників міцності при стиску – до 24 МПа у віці 28 днів.

Також слід зазначити, що всі досліджувані бетони характеризуються низькою міцністю на згин, що свідчить про необхідність подальших досліджень та підбору складу суміші для підвищення міцнісних властивостей бетону на основі рециркульованих заповнювачів.

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