Study of influence of organic pollutants on alkali activated cements based on recycled aggregates

Victoria Zozulynets[1], Valentyna Grabovchak[2]
Vasyl Ivanychko[3], Igor Papuch[4]

[1,2,3,4]Kyiv National University of Construction and Architecture,
Povitrianykh Syl ave, 31, Kyiv, Ukraine, 03037

[1]zozulynets.vv@knuba.edu.ua, https://orcid.org/0000-0002-8066-2033
[2] grabovchak.vv@knuba.edu.ua, https://orcid.org/0000-0002-6315-9639
[3]ivanychko32@gmail.com, https://orcid.org/0000-0002-4384-6490
[4]papuch_il-2022@knuba.edu.ua, https://orcid.org/0009-0008-4153-3889

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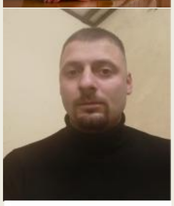
Viktoria ZOZULYNETS

Senior researcher of SRIBM
PhD (Eng.)

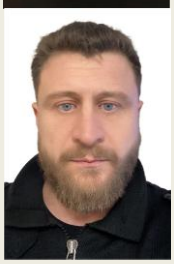
Valentyna Grabovchak

Associate professor
PhD (Eng.)



Vasyl IVANYCHKO

Senior officer of the engineering support research department of military unit A4983



Igor PAPUCH

PhD student

Abstract. The issue of the presence in the structure of recycled aggregate of residues of organic compounds, unburned carbon particles, wood and other pollutants, which are characteristic of the waste of destruction of reinforced concrete structures formed as a result of hostilities, definitely needs to be resolved. It is for this purpose that a study was conducted to determine the influence of organic compounds, namely sawdust, on the physical and mechanical characteristics of alkali-activated concretes made using recycled aggregates.

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

. The additional introduction of sawdust in the amount of 3% and 5% leads to a decrease in the strength of concrete both in flexure and in compression. However, for systems with 100% granite aggregate content, the percentage of strength reduction is greater compared to compositions that include recycled aggregate. And for systems that include exclusively recycled aggregate, the compressive strength increases by 1 MPa (26.2 MPa, composition No. 10) with a content of 3% sawdust and by

0.6 MPa (25.8 MPa composition No. 15) with a content of 5%.

The results show that the use of recycled aggregate, although it causes a decrease in the physical and mechanical characteristics of concrete, the correct selection of the percentage content of the mixture components allows you to control the specified characteristics of concrete, in particular, flexure and compression strength.

Keywords: concrete, alkali-activated cement, recycling, aggregates, organic admixtures.

INTRODUCTION

In the construction industry, cementitious materials, and especially concrete, are the most widely used building materials [1-4]. From a mechanical point of view, concrete is characterized by quite high compressive strength (10–65 MPa) compared to other materials. In addition, concrete is one of the most versatile materials used in construction, allowing design engineers to optimize application requirements with many possible structural configurations. Despite this, the growing demand for concrete also puts pressure on aggregate extraction, water and cement production. Considering the above, the secondary use of concrete in the form of recycled aggregates is a promising direction for the development of the construction industry, which will have a positive impact on the country's economy and solve the issue of large-scale construction waste [5-8].

On the other hand, the use of hybrid alkaline cements is effective for general construction and special-purpose materials, namely in the manufacture of concrete mixtures and concretes based on them with an increased risk of structural loosening due to the increased content of organic residues and combustion products [9-12]. Materials based on them are able to withstand significant effects of swelling-shrinkage deformations caused by the presence of combustion products and organic residues. This allows us to predict the effectiveness of their introduction for controlling the processes of structure formation of concretes based on recycled aggregates [13-17].

The works [18-21] highlight the results of studies of the chemical interaction between organic and inorganic substances, which allow creating materials with desirable properties for construction. Such properties include chemical stability, limited shrinkage and high mechanical strength. Although the number of studies investigating the use of biomolecules in concrete is increasing, very little has focused on the chemical mechanisms of organic-inorganic interactions. The apparent limited interest in this area of research may be the reason for its underexplored potential for addressing environmental challenges in civil engineering.

This study aims to generate further interest in the study of organic-inorganic interactions and provide practical applications for civil engineering.

PURPOSE OF THE STUDY

The aim of the work is to develop concrete mixtures and concretes based on them with a low-defect macrostructure under the condition of using recycled aggregates.

One of the ways to achieve this goal is to use alternative binders, namely alkali-activated cements, which are able to withstand increased structural fluctuations that occur due to the presence of organic impurities.

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.

Wood sawdust with a particle size of 3 to 6 mm was used as an organic additive.

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

Two types of coarse aggregate were used in the study: granite and recycled with a fraction of 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 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.

Physical-mechanical tests of alkaline cement were carried out in accordance with DSTU B V.2.7-185:2009, DSTU B V.2.7-187:2009, DSTU B V.2.7-188:2009, which included the determination of the normal density of cement paste, hardening time, compressive and flexural strength limits of cement stone and fineness of cement grinding.

The study of the features of the processes of cement structure formation was carried out using a complex of physical-mechanical and physical-chemical research methods on samples of artificial stone.

The specific surface area of the initial crushed raw material components and finished cements was determined using the Blaine device.

The determination of the flexural strength of concrete was carried out on prism samples measuring 100x100x400 mm, and the determination of the compressive strength was carried out on cube samples with an edge size of 100 mm according to DSTU B V.2.7-223:2009. The samples hardened under normal conditions (20±2ºC and relative humidity 95±5%). The control periods for determining the strength were 7 and 28 days, since previous studies had established the classification of slag-alkali cement used in the manufacture of control compositions of the concrete mixture as M400 (45.3 MPa at 28 days of hardening). In addition, the determination of the flexural and compressive strength of the samples after heat-moisture treatment was carried out according to the following regime: temperature increase for 2 hours, holding at a temperature of 75 ºC for 5 hours and slow cooling for 3 hours.

RESULTS AND EXPLANATIONS

At this stage of the research, tests were conducted with partial and complete replacement of granite aggregate with recycled aggregate, and additional introduction of sawdust as an organic additive in the amount of 3% (Table 1, systems 6-10) and 5% (Table 1, systems 11-15) of the cement mass

The results of the conducted research are given in Table 2.

According to the results obtained, the use of recycled aggregate in the composition of concrete mixtures significantly reduces the physical and mechanical performance of concretes based on them. Thus, with a 100% content of traditional granite aggregate, the system is characterized by a compressive strength index at 28 days of hardening, which is 38.5 MPa, which, taking into account the coefficient of variation of 8%, corresponds to the concrete class C30/35. While 100% use of recycled aggregate results in a decrease in compressive strength to 25.2 MPa and concrete class C16/20, respectively.

The use of mixed aggregate, represented by both traditional granite (50%) and recycled (50%) aggregate, results in concrete with a compressive strength of 31.1 MPa (concrete class C20/25), and with an increase in the content of granite aggregate to 70%, this indicator increases to 34.3 MPa, which corresponds to the concrete class C25/30. As for the flexural strength of concrete samples, with an increase in the percentage of recycled aggregate in the composition of the concrete mixture, this indicator also decreases. Thus, with a 100% granite crushed stone content, the flexural strength at 28 days of hardening is 7.1 MPa, with a replacement of half of the composition with recycled crushed stone, this indicator decreases to 6.3 MPa, and with a complete replacement it is 3.6 MPa.

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

№	Binder, kg			Aggregate 5-20 mm, kg		Sand, kg	W/C	Sawdust, kg
	Slag	$Na_2SiO_3 \cdot 2H_2O$	Na_2SiO_4	granite	recycled			
1	304.5	28	17.5	1100	-	750	0.5	-
2	304.5	28	17.5	770	330	750	0.5	-
3	304.5	28	17.5	550	550	750	0.5	-
4	304.5	28	17.5	330	770	750	0.5	-
5	304.5	28	17.5	-	1100	750	0.5	-
6	304.5	28	17.5	1100	-	750	0.5	10.5
7	304.5	28	17.5	770	330	750	0.5	10.5
8	304.5	28	17.5	550	550	750	0.5	10.5
9	304.5	28	17.5	330	770	750	0.5	10.5
10	304.5	28	17.5	-	1100	750	0.5	10.5
11	304.5	28	17.5	1100	-	750	0.5	17.5
12	304.5	28	17.5	770	330	750	0.5	17.5
13	304.5	28	17.5	550	550	750	0.5	17.5
14	304.5	28	17.5	330	770	750	0.5	17.5
15	304.5	28	17.5	-	1100	750	0.5	17.5

Table 2. Service properties of concretes under study

No	Flexural strength, MPa		Compressive strength, MPa		Mean density, kg/m^3
	7 days	28 days	7 days	28 days	
1	6.0	7.1	21.9	38.5	2305
2	5.3	6.6	17.8	34.3	2295
3	5.0	6.3	15.9	31.1	2265
4	4.5	5.1	13.5	28.9	2260
5	2.5	3.6	13.1	25.2	2250
6	5.8	6.9	21.3	33.9	2240
7	5.2	6.6	16.9	32.1	2290
8	4.9	6.1	14.2	30.7	2250
9	4.0	4.7	12.8	28.2	2240
10	2.5	3.6	12.3	26.2	2240
11	5.5	6.7	19.2	32.6	2250
12	5.3	6.1	16.9	31.7	2230
13	4.9	5.5	14.8	30.4	2225
14	3.6	4.3	13.2	27.9	2220
15	2.4	3.4	12.1	25.8	2210

The results show that the use of recycled aggregate, although it causes a decrease in the physical and mechanical properties of concrete, but the correct selection of the percentage of the mixture components allows you to control the specified characteristics of concrete, in particular, the flexural and compressive strength.

The introduction of sawdust to determine the influence of organic compounds in the structure of concrete on its operational properties gave the following results. The content of sawdust in the amount of 3% and 5% leads to a decrease in the strength of concrete both in flexural and compressive strength. However, for systems with 100% granite aggregate, the percentage of strength reduction is greater compared to compositions that include recycled aggregate. And for systems that include only recycled aggregate, the compressive strength increases by 1 MPa (26.2 MPa, composition No. 10) with a 3% sawdust content and by 0.6 MPa (25.8 MPa composition No. 15) with a 5% content. This is probably due to the fact that at the stage of preparing the concrete mix, the sawdust absorbed some of the water, which ensured the structure of the artificial stone, along with the increased water demand of the recycled aggregate. The average density of samples based on granite aggregate is 2300 kg/m3. With an increase in the content of recycled aggregate in the material, its average density decreases. For samples made using recycled aggregate, the average density is 2200 kg/m3. This indicates the presence of additional pores and voids and the general defectiveness of the structure of the recycled aggregate, which not only affects the reduction of strength indicators, but also, most likely, will lead to a decrease in frost resistance and durability of concrete in general.

Figure 1 shows the strength indicators of the component compositions of concrete based on alkali-activated binder and recycled aggregate after heat treatment.

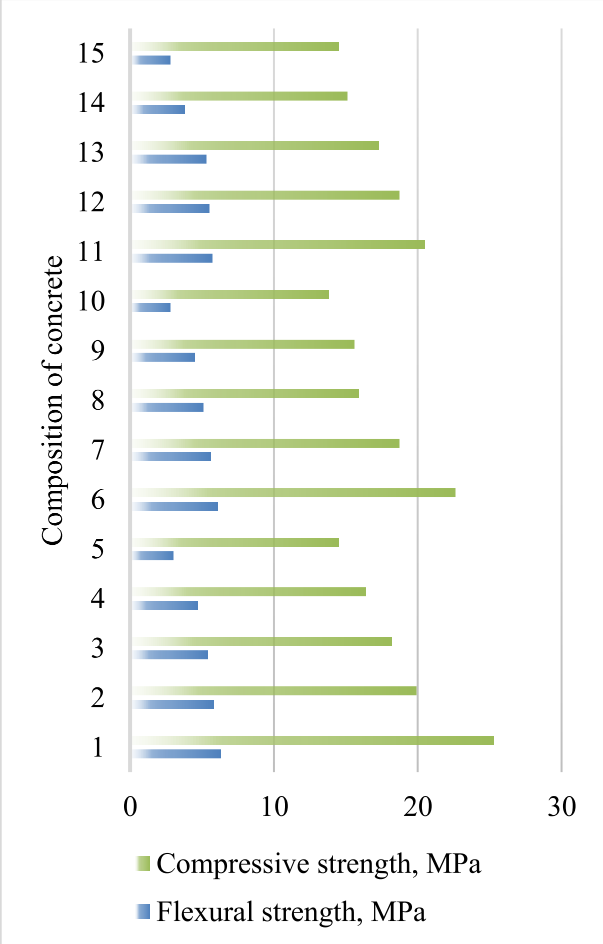


Figure 1. Flexural and compressive strength of the concretes after thermal curing

According to the obtained thermo-humidity data, processing according to the 2+5+3 regime allows obtaining concrete with a strength that is 55-65% of the design strength and is close to the strength indicators on the 7th day of hardening of the samples under normal conditions.

CONCLUSIONS

Hybrid alkaline cements are effective for general and special-purpose construction materials, particularly in the production of concrete mixtures and concretes with an increased risk of structural loosening due to high levels of organic residues and combustion products. These materials can withstand significant swelling and shrinking deformations caused by the presence of combustion products and organic residues. This makes it possible to predict the effectiveness of introducing them to control concrete structure formation processes based on recycled aggregates.

This study analyzed the effects of replacing granite aggregate with recycled aggregate and adding sawdust as an organic additive to concrete mixtures. The results showed that the use of recycled waste aggregate worsens the physical and mechanical properties of concrete, in particular its compressive and flexural strength. For example, replacing all granite aggregate with recycled aggregate reduces the compressive strength of concrete from 38.5 MPa to 25.2 MPa, which corresponds to a decrease in the concrete class from C30/35 to C16/20.

The addition of sawdust (at 3% and 5%) to the concrete composition also reduces its strength, but this effect is less pronounced for concrete based on recycled aggregate. It is noteworthy that sawdust can slightly positively affect the strength indicators, especially in compositions with 100% recycled aggregate content.

The average density of the resulting material decreases with increasing recycled aggregate content, indicating porosity and structural defects in the aggregate. This can negatively affect the durability of the concrete, especially its frost resistance. Overall, the study shows that choosing the right components and proportions in the concrete mix optimizes its performance, even when using recycled aggregate and organic additives.

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REFERENCES

1. **Kovalchuk, O., Zozulynets, V., Popruha, P., & Grabovchak, V. (2025).** Mix design of the composition of general construction concrete based on recycled aggregates. *Eastern-European Journal of Enterprise Technologies*, 5(6 (137), 49–57. DOI:10.15587/1729-4061.2025.340832
2. **Kovalchuk, O., Zozulynets, V., Ivanychko, V., & Kopotun, R.** (2025). Vykorystannia retsyrkulovanykh zapovniuvachiv – shliakh do stiikoho vidnovlennia**.** *Ways to Improve Construction Efficiency*, 1(54), 164–171. DOI:10.32347/2707-501x.2024.54(1).164-171
3. **Grabovchak, V., Kovalchuk, O., Kopotun, R., & Hrabovchak, V.** (2025). Doslidzhennia mozhlyvostei vykorystannia retsyrkulovanykh vidkhodiv yak komponentiv betonnykh sumishei u konteksti pryntsypiv staloho budivnytstva. *Airport Planning, Construction and Maintenance Journal*, (1), 34–40. DOI:10.32782/apcmj.2025.1.4
4. **Kryvenko, P., Rudenko, I., Sikora, P., Sanytsky, M., Konstantynovskyi, O., & Kropyvnytska, T. (2024).** Alkali-activated cements as sustainable materials for repairing building construction: a review. *Journal of Building Engineering*, 90, 109399..
5. **Kryvenko, P., Rudenko, I., Konstantynovskyi, O., & Kovalchuk, A. (2024).** Improvement of Early Strength of Slag Containing Portland Cements. In *Hydraulic and Civil Engineering Technology IX* (pp. 515-521). IOS Press.
6. **Peng, Y., Cai, S., Huang, Y., & Chen, X. F.** (2025). Recycled Aggregates for Sustainable Construction: Strengthening Strategies and Emerging Frontiers. *Materials*, *18*(13), 3013. DOI: 10.3390/ma18133013
7. **Yanez, S., Márquez, C., Valenzuela, B., & Villamar-Ayala, C. A.** (2022). *A Bibliometric-Statistical Review of Organic Residues as Cementitious Building Materials. Buildings 2022, 12, 597*. DOI: 10.3390/buildings12050597
8. **Liu, L., Yang, X., Feng, S., Chen, J., Dang, Y., Wu, B., ... & Li, M.** (2025). Research on the disintegration performance of fibre-reinforced vegetative cement-soil (VCS). *Case Studies in Construction Materials*, *22*, e04437. DOI: 10.1016/j.cscm.2025.e04437
9. **Krivenko, P., Petropavlovskyi, O., Kovalchuk, O., Lapovska, S., Pasko, A.** (2018) Design of the composition of alkali activated portland cement using mineral additives of technogenic origin. *Eastern-European Journal of Enterprise Technologies*, № 4(6), 6-15. DOI: 10.15587/1729-4061.2018.140324
10. **Aluko, O. G., Yatim, J. M., Kadir, M. A. A., Yahya, K. (2020).** A review of properties of biofibrous concrete exposed to elevated temperatures. *Construction and Building Materials*, 260, 119671.

11. **Bu, C., Liu, L., Lu, X., Zhu, D., Sun, Y., Yu, L., ... & Wei, Q.** (2022). The durability of recycled fine aggregate concrete: A review. *Materials*, 15(3), 1110. DOI: 10.3390/ma15031110
12. **Troian, V., Gots, V., Keita, E., Roussel, N., Angst, U., & Flatt, R. J.** (2022). Challenges in material recycling for postwar reconstruction. *RILEM Technical Letters*, 7, 139-149. DOI:10.21809/rilemtechlett.2022.171
13. **Krivenko, P., Kovalchuk, O., & Boiko, O.** (2019, December). Practical experience of construction of concrete pavement using non-conditional aggregates. *In IOP Conference Series: Materials Science and Engineering* (Vol. 708, No. 1, p. 012089). IOP Publishing. DOI: 10.1088/1757-899X/708/1/012089
14. **Kochova, K., Gauvin, F., Schollbach, K., Brouwers, H. J. H.** (2020). Using alternative waste coir fibres as a reinforcement in cement-fibre composites. *Construction and Building Materials,* 231, 117121. DOI: 10.1016/j.conbuildmat.2019.117121
15. **Khasanov, B., Irmuhamedova, L., Firlina, G., & Mirzaev, T.** (2020, June). Theoretical foundations of the structure formation of cement stone and concrete. *In IOP Conference Series: Materials Science and Engineering* (Vol. 869, No. 3, p. 032032). IOP Publishing.
16. **Fu, X., Ye, W. J., Yuan, G., Zhang, X. L., & Niu, R. Y.** (2025). Experimental study on mechanical properties of cured sand combined with plant-based bio-cement (PBBC) and organic materials. *Applied Biochemistry and Biotechnology*, *197*(3), 1865-1888.
17. **Luo, M., Zhao, Y., Ji, A., & Ding, Z.** (2025). Enhancing recycled aggregates quality through biological deposition treatment. *Journal of Building Engineering*, *100*, 111681. DOI: 10.1016/j.jobe.2024.111681
18. **Spencer, P., Li, H., Hocknull, S., Chalmers, G., & Wang, T. (2025).** Exploring mineral–organic interactions for eco-friendly concrete alternatives: a radical concept. *RSC Sustainability*, *3*(5), 2064-2078. DOI: 10.1039/D4SU00696H
19. **Barbieri, V., Gualtieri, M. L., Siligardi, C.** (2020). Wheat husk: A renewable resource for bio-based building materials. *Construction and Building Materials*, 251, 118909. DOI: 10.1016/j.conbuildmat.2020.118909
20. **Erkmen, L., Yavuz, H. I., Kavci, E., Sari, M.** (2020). A new environmentally friendly insulating material designed from natural materials. *Construction and Building Materials*, 255, 119357. DOI:10.1016/j.conbuildmat.2020.119357
21. **Bayraktar, O. Y., Turhal, S., Benli, A., Shi, J., & Kaplan, G. (2025).** Application of recycled aggregates and biomass ash in fibre-reinforced green roller compacted concrete pavement-technical and environmental assessment. *International Journal of Pavement Engineering*, *26*(1), 2458140. DOI: 10.1080/10298436.2025.2458140

Дослідження впливу органічних сполук на лужні бетони на основі рециркульованих заповнювачів

Вікторія ЗОЗУЛИНЕЦЬ,
Валентина ГРАБОВЧАК,
Василь ІВАНИЧКО,
Ігор ПАПУЧ

Анотація. Питання наявності у структурі рециркульвоного 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 безумовно потребує вирішення. Саме з цією метою було проведено дослідження з визначення впливу органічних сполук, а саме тирси на фізико-механічні характеристики лужноактивованих бетонів виготовлених з використанням рециркульованих заповнювачів.

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.

Додаткове введення тирси у кількості 3% та 5% приводить до зниження показників міцності бетону як на згин так і на стиск. Проте для систем зі 100% вмістом гранітного заповнювача відсоток зниження міцності є більшим у порівнянні зі складами до складу яких входить

рециркульований заповнювач. А для систем до яких входить виключно рециркульований заповнювач показник міцності на стиск підвищується на 1 МПа (26,2 МПа, склад №10) при вмісті 3% тирси та на 0,6 МПа (25,8 МПа склад №15) при вмісті 5%.

Наведені результати засвідчують, що використання рециркульованого заповнювача хоч і обумовлює зниження фізико-механічних показників бетону, але правильний підбір відсоткового вмісту компонентів суміші, дозволяє керувати заданими характеристиками бетону, зокрема міцністю на згин та стиск.

Ключові слова: бетон, лужно-активований цемент, рециркуляція, заповнювачі, органічні домішки.