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DRY BUILDING MIXTURES BASED ON RECYCLED CONSTRUCTION WASTE PRODUCTS FOR THE RESTORATION OF BUILDINGS AND INFRASTRUCTURE

[1]**Bondar A.V.**, PhD, Associate Professor,
bondarav@vntu.edu.ua, ORCID: 0000-0002-8098-1181
[1]**Kucherenko L.V.**, PhD, Associate Professor,
liliya13liliya13@gmail.com, ORCID: 0000-0003-0348-3610
[2]**Babii I.M.**, PhD, Associate Professor,
igor7617@gmail.com, ORCID: 0000-0001-8650-1751
[1]**Bondar O.V.**, postgraduate student,
[1]*Vinnytsia National Technical University*
Khmelnytske Shose, 95, Vinnytsia, 21021, Ukraine
[2]*Odessa State Academy of Civil Engineering and Architecture*
Didrikhsona St., 4, Odesa, 65029, Ukraine

Abstract. The paper investigates the potential use of recycled construction waste products in dry building mixtures intended for the restoration of buildings and infrastructure. The relevance of the study is determined by the considerable quantities of construction waste generated as a result of the demolition of obsolete structures, reconstruction of buildings, and destruction caused by military operations in Ukraine. The rational use of secondary mineral raw materials represents a promising approach to resource conservation, reduction of environmental impacts, and improvement of the efficiency of post-war reconstruction.

The current state of construction waste recycling in the production of building materials is analysed. The potential application of fillers derived from crushed concrete, brick waste, waste glass, and crushed limestone by-products as components of dry building mixtures is considered. The physical and mechanical characteristics of the raw materials are presented, and a series of experimental compositions with different contents of secondary components is developed.

The effect of the amount of recycled materials on the technological and performance properties of dry building mixtures is evaluated. It is established that an increase in the proportion of secondary components contributes to an improvement in the water-retention capacity of the mixtures and a reduction in their average density. At the same time, excessive amounts of recycled raw materials result in a decrease in the strength characteristics of the material. Based on the experimental results, optimal mixture compositions are determined, providing compressive strength of up to 29.5 MPa, flexural strength of up to 6.4 MPa, and adhesion strength of up to 0.86 MPa.

The possibility of reducing cement consumption by up to 25% in the optimal compositions without a significant deterioration in the performance properties of the material is investigated.

The obtained results confirm the feasibility of using the developed dry building mixtures for repair and restoration works, the construction of levelling layers, the repair of concrete and brick surfaces, as well as the restoration of residential, public, and engineering and transport infrastructure.

Keywords: dry building mixtures, construction waste, recycling, repair and restoration works, post-war reconstruction, technological and performance properties, resource conservation, building materials.

Introduction. The construction industry is one of the largest consumers of natural resources and, at the same time, one of the major sources of waste generation. According to international studies, construction and demolition waste accounts for up to 30-40% of the total volume of solid waste in developed countries [1, 2]. A significant proportion of such waste consists of concrete, reinforced concrete, bricks, ceramics, and other mineral materials which, after appropriate processing, can be reused as secondary raw materials in the production of new building materials [3-10].

In Ukraine, the issue of efficient construction waste management has become particularly important due to the large-scale destruction of residential, public, industrial, and infrastructure facilities caused by military operations (Table 1). The extensive destruction of buildings and structures has generated millions of tons of construction debris (Fig. 1), the disposal of which requires considerable financial resources and substantial areas for storage. At the same time, the reconstruction of the country will require large quantities of building materials, the production of which has traditionally been associated with the intensive consumption of natural resources and considerable energy expenditure [10-13].

Table 1 – Prerequisites for the use of recycled construction waste products in the production of dry building mixtures

Causes of waste generation	Problems associated with waste accumulation	Proposed solutions
Demolition of obsolete and structurally unsafe buildings and structures	Occupation of substantial areas for waste storage	Sorting and processing of construction debris for reuse
Destruction of buildings and structures as a result of military operations	Generation of millions of tons of demolition waste and difficulties in restoring affected areas	Establishment of regional construction waste recycling centres
Reconstruction and modernisation of the housing stock	Increasing pressure on solid-waste landfills	Use of secondary raw materials in the production of building materials
Intensive development of the construction industry	Depletion of natural reserves of sand, crushed stone, and other mineral resources; increase in the proportion of defective construction products	Partial replacement of natural raw materials with recycled products
Manufacturing waste and residues of building materials	Increased costs of waste transportation and disposal	Reuse of materials after crushing and sorting
Growing demand for building materials for national reconstruction	Increasing costs of primary raw materials and construction products	Use of locally available secondary resources for the production of dry building mixtures
Accumulation of waste in areas affected by destruction	Difficulties in restoring residential areas and infrastructure facilities	Integrated use of waste-processing products during territorial reconstruction

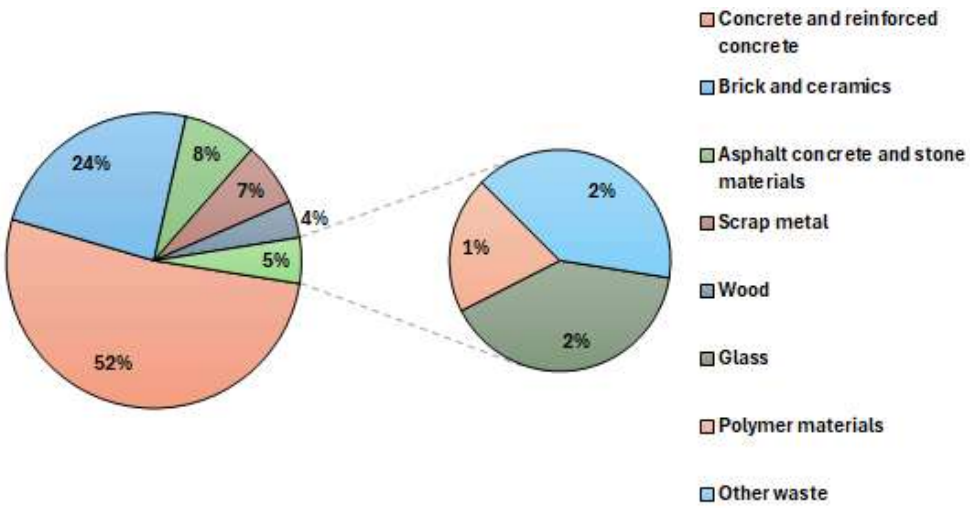


Fig. 1. Morphological composition of demolition waste in Ukraine

As shown in Fig. 1, concrete and reinforced-concrete structures constitute the largest proportion of demolition waste in Ukraine (52%), followed by brick and ceramic waste (24%). The total proportion of mineral waste exceeds 80%, indicating considerable potential for its utilisation as a secondary raw material in the production of building materials, particularly dry building mixtures (DBMs), repair compositions, and road construction materials [11-13].

Dry building mixtures are of particular interest because they are widely used for masonry, plastering, repair, levelling, waterproofing, and road construction works. The incorporation of products obtained from the processing of concrete and brick debris, as well as other technogenic materials, into dry building mixtures (Table 2) makes it possible to reduce the consumption of natural raw materials, lower production costs, and improve the environmental efficiency of construction [11, 14-18].

Table 2 – Main types of secondary raw materials for the production of dry building mixtures

Type of secondary raw material	Waste source	Potential application in DBMs
Crushed concrete waste	Demolition of buildings and structures	Fine aggregate, microfiller
Crushed brick waste	Demolition of brick structures, ceramic manufacturing waste	Filler for plastering and mineral mixtures
Fly ash	Thermal power plants	Active mineral additive
Granulated blast-furnace slag	Metallurgical industry	Mineral additive for cementitious compositions
Stone-processing waste	Quarries and stone-processing enterprises	Microfiller
Cement dust	Cement plants	Active mineral component
Concrete crushing fines	Demolition of buildings and structures	Filler for repair and road-building mixtures
Ceramic waste	Ceramic production and building demolition	Pozzolanic additive
Crushed glass and glass waste	Building demolition, glass production, window structures, household waste	Finely ground microfiller, pozzolanic additive, decorative filler

Analysis of recent research and publications. The reuse of construction waste is one of the most relevant areas of modern construction materials science. This issue has become particularly important in Ukraine due to the large-scale destruction, which necessitates the simultaneous management of construction debris and provision of material resources for reconstruction [11-15].

The possibility of incorporating secondary mineral resources into cementitious compositions, concrete, mortars, and dry building mixtures is being continuously investigated by both Ukrainian and international researchers. However, the integrated utilisation of recycled construction waste products in the manufacture of dry building mixtures specifically intended for the post-war restoration of buildings and infrastructure remains insufficiently investigated and requires further research [7, 17-20].

The theoretical principles underlying the use of technogenic waste in the production of building materials have been addressed in the works of L.Y. Dvorkin, A.V. Myronenko, P.V. Kryvenko, K.K. Pushkarova, V.P. Kovalskyi, O.V. Bereziuk, and other researchers. These studies have demonstrated that ash-and-slag materials, stone-processing waste, sludge from mining and beneficiation enterprises, and products obtained from construction waste processing can be effectively utilised as components of composite building materials, contributing to resource conservation and reduced production costs [15, 19, 21-23].

Studies by A.V. Bondar, V.P. Kovalskyi, V.V. Zhytkovskyi, and A.V. Myronenko have demonstrated the feasibility of incorporating fly ash from thermal power plants, stone-processing waste, and other technogenic products into dry building mixtures. It has been established that the introduction of active mineral components improves the particle-size distribution of mixtures, densifies the cement matrix, reduces cement consumption, and enhances material durability [14, 18, 19].

Other Ukrainian researchers have investigated technologies for processing concrete and brick waste and identified promising approaches to their utilisation in the manufacture of building materials. It has been established that, following sorting, crushing, and fractionation, secondary mineral materials can be used as aggregates in concrete, mortars, and dry mixtures, thereby reducing waste volumes and the consumption of natural resources [24, 25].

Studies investigating the use of concrete and reinforced-concrete waste as recycled aggregates have established that residues of hydrated cement paste remain on the surfaces of crushed concrete particles and can participate in subsequent structure-forming processes. Therefore, recycled products may be regarded not only as inert fillers but also as active components of composite materials. Materials produced using such recycled components can achieve strength characteristics sufficient for use in repair, masonry, and road-building mixtures [26, 27].

In addition to domestic research, considerable attention is being paid to construction waste recycling in the European Union, the United States, Japan, and China. According to international studies, construction and demolition waste accounts for more than 30% of the total solid waste generated, while recycling and reuse rates exceed 80% in some EU countries [1, 2]. It has been established that recycled aggregates derived from concrete and brick waste can effectively replace natural mineral materials in construction composites, provided that they are appropriately processed and their physical and mechanical characteristics are adequately controlled [3-9].

Recent international studies also demonstrate the potential of using finely dispersed products obtained from crushing construction waste as microfillers and pozzolanic components. Finely ground concrete and brick powders have been found to increase the density of the cement matrix, reduce capillary porosity, and improve the durability of composite materials [7-9].

Following the beginning of the full-scale war in Ukraine, a distinct research area has emerged focusing on the utilisation of construction waste for post-war territorial recovery. Studies by L.V. Kucherenko, I.M. Babii, O.V. Khrystych, I.N. Dudar, and other researchers emphasise the need to implement integrated approaches to the reconstruction of cities and transport infrastructure. Such approaches should include the efficient utilisation of recycled construction debris as one of the principal locally available resources for restoring destroyed areas [10-13, 26, 27].

Thus, the analysis of existing research demonstrates the considerable potential of recycled construction waste products in dry building mixture technology. Nevertheless, most existing studies focus on the utilisation of secondary materials in concrete and mortars, whereas the development of dry building mixtures intended for the restoration of residential, public, and infrastructure facilities remains insufficiently investigated [5, 9, 14, 17].

The aim of this study is to investigate the effects of recycled construction waste products on the properties of dry building mixtures and to determine effective compositions of composite materials suitable for the restoration of buildings and infrastructure.

The main objectives of the study are as follows: to analyse current approaches to the utilisation of recycled construction waste products in the production of dry building mixtures; to develop experimental compositions of dry building mixtures incorporating products derived from recycled concrete, brick, and glass waste; to determine the effect of the content of secondary components on the technological and performance properties of the mixtures; to establish optimal compositions of dry building mixtures for repair and restoration applications; and to assess their potential use in post-war reconstruction.

Materials and research methods. The materials used in the study included Portland cement, mineral fillers, and recycled construction waste products in the form of crushed concrete, brick, and glass waste. Experimental investigations were conducted in accordance with applicable standards for determining particle-size distribution, water demand, consistency of mortar mixtures, average density, compressive strength, and other physical and mechanical properties. The experimental data were processed using mathematical statistics and comparative analysis.

Main results and discussion. The recycled construction waste products used as components of the dry building mixtures were obtained by crushing and sorting concrete debris, brick waste, and waste glass originating from building demolition (Table 3). Portland cement PC I-500N was used as

the binder, while quartz sand with a fineness modulus of 1.8-2.0 was used as the reference fine aggregate. Sand produced by crushing limestone, with a fineness modulus of ≤0.4, was also used as a filler (Table 4). The utilisation of limestone crushing products contributes to the rational use of mineral resources and reduces the amount of waste generated during the extraction and processing of natural stone.

Following mechanical processing, the secondary raw materials were dried to constant mass and ground to a particle size of ≤1.25 mm. The resulting materials were used as mineral fillers and active components of the dry building mixtures.

Table 3 – Properties of recycled construction waste products

Property	Crushed concrete	Crushed brick	Crushed glass
Bulk density, kg/m³	1280	1160	1420
True density, kg/m³	2450	2210	2490
Water absorption, %	6.4	12.1	0.4
SiO_2 content, %	48.3	61.8	72.4
CaO content, %	24.5	3.8	9.2
Al_2O_3 content, %	7.2	18.6	1.8
Specific surface area, m²/kg	320	410	450

As shown in Table 3, crushed concrete is characterised by a relatively high content of calcium compounds and residual hydrated cement paste, which may positively affect the structure formation of cementitious composites. Crushed brick contains a significant amount of amorphous silica and aluminium oxides and therefore exhibits pozzolanic activity. Crushed glass has the highest silica content and can be used as a finely dispersed microfiller.

According to the properties of the aggregates presented in Table 4, crushed limestone sand is characterised by a high calcium carbonate content, a relatively large specific surface area, and angular particle morphology. These characteristics improve contact between the filler particles and the cement matrix, which may positively affect the strength and adhesion properties of dry building mixtures. This produces a microfilling effect, contributes to densification of the cement matrix, and improves the interfacial transition zone between the cement matrix and aggregate particles [14, 18, 19].

Furthermore, calcium carbonate may act as a nucleation site for cement hydration products, thereby positively affecting early-age strength and the technological properties of the mixtures. Therefore, crushed limestone sand was considered a promising component of dry building mixtures intended for repair and restoration applications. However, its increased specific surface area results in greater water demand as the limestone filler content increases.

Table 4 – Properties of materials used in dry building mixtures

Property	PC I-500N	Quartz sand	Limestone filler
Bulk density, kg/m³	1100	1550	1150
True density, kg/m³	3100	2630	2700
Specific surface area, m²/kg	320-350	115	250-450
Fineness modulus	-	1.8-2.0	0.1-0.4
Moisture content, %	≤0.5	≤1.0	≤1.0
Water absorption, %	-	0.8	0.5-1.0
SiO_2 content, %	20-24	96.5	4.2
CaO content, %	62-67	1.2	52-55*
$CaCO_3$ content, %	-	1.5	90-98
Al_2O_3 content, %	4-8	0.8	0.5-1.5
Primary function in the mixture	Binder	Fine aggregate	Mineral filler

*expressed as calcium oxide equivalent

To evaluate the effect of waste materials on the properties of dry building mixtures, a series of experimental compositions was prepared. The Portland cement content was maintained constant at 30% in all compositions. Recycled construction waste products were introduced by partially replacing quartz sand while maintaining a constant cement content (Table 5). Composition 0 served as the reference mixture and contained only conventional components, namely Portland cement and quartz sand. The total content of dry components in each composition was 100%.

This approach made it possible to evaluate the effects of secondary fillers on the technological properties of the dry mixtures, including water demand, average density, compressive strength, and other performance characteristics. Compositions 1-8 were designed to evaluate the effects of individual types of secondary raw materials, whereas compositions 9-11 were used to analyse the combined effects of crushed concrete, crushed brick, crushed glass, and limestone filler.

Table 5 – Experimental compositions of dry building mixtures containing recycled construction waste products

Composition No.	PC I-500N, %	Quartz sand, %	Crushed, %			Limestone crushing-product filler, %	Water demand, % by mass of dry mixture
			crushed concrete	crushed brick	crushed glass		
0	30	70	0	0	0	0	16.0
1	30	65	5	0	0	0	16.5
2	30	60	10	0	0	0	17.0
3	30	65	0	10	0	0	17.2
4	30	60	0	10	0	0	18.0
5	30	65	0	0	5	0	15.8
6	30	60	0	0	10	0	15.5
7	30	65	0	0	0	5	16.3
8	30	60	0	0	0	10	16.8
9	30	50	5	5	5	5	17.0
10	30	40	10	10	5	5	17.8
11	30	30	10	10	10	10	18.2

The water demand values were determined to ensure the same consistency of the mortar mixtures (flow diameter of 150 ± 5 mm). Increasing the content of crushed concrete, and particularly crushed brick, resulted in higher water demand due to their developed porous structure and increased water absorption. In contrast, the incorporation of crushed glass slightly reduced water demand because of the smooth particle surfaces and low water absorption. The filler obtained from crushed limestone caused a moderate increase in water demand owing to the increased specific surface area of the mixture.

To determine the physical and mechanical properties, the dry components were initially mixed until homogeneous. The calculated amount of water was subsequently added, and the mortar was prepared using a laboratory mortar mixer. The resulting mortars were placed in standard metal moulds to produce 40 × 40 × 160 mm prismatic specimens. The mixtures were compacted on a laboratory vibrating table.

After casting, the specimens were kept in the moulds for 24 h at a temperature of (20 ± 2) °C and a relative humidity of at least 95%, after which they were demoulded. The specimens were subsequently cured under standard conditions at a temperature of (20 ± 2) °C and a relative humidity of at least 95% for 28 days. At the end of the curing period, water-retention capacity, average density, flexural strength, compressive strength, and adhesion strength were determined in accordance with the applicable standard test methods [28].

The results presented in Table 6 are mean values obtained from tests conducted on a series of specimens for each composition [20, 29].

Table 6 – Physical and mechanical properties of dry building mixtures containing recycled construction waste products

Composition No.	Water-retention capacity, %	Average mortar density, kg/m³	28-day compressive strength, MPa	28-day flexural strength, MPa	Adhesion strength, MPa
0	95.0	1980	28.5	6.2	0.82
1	95.8	1965	28.0	6.1	0.80
2	96.5	1945	27.2	5.9	0.78
3	96.8	1935	26.8	5.8	0.77
4	97.5	1910	25.5	5.5	0.74
5	94.8	1975	29.0	6.3	0.84
6	94.5	1970	29.5	6.4	0.86
7	95.5	1960	28.3	6.2	0.83
8	96.0	1948	27.8	6.0	0.81
9	96.5	1930	27.0	5.9	0.79
10	97.2	1905	25.8	5.6	0.75
11	98.0	1880	24.5	5.3	0.72

The experimental results demonstrate that the incorporation of recycled concrete and crushed brick fillers is accompanied by a gradual decrease in mortar density and strength, which is associated with the higher porosity of the secondary materials (Figs. 2-4). At the same time, the water-retention capacity of the mixtures increases due to the greater absorption capacity of the porous recycled aggregates. The use of crushed glass results in a slight increase in strength due to its dense structure and the possible pozzolanic activity of the finely dispersed glass fraction. The filler derived from crushed limestone products has practically no adverse effect on the strength characteristics of the mixtures and contributes to densification of the cement matrix.

Based on the experimental results, a significant effect of the content of secondary components on the technological and performance properties of dry building mixtures was established. In particular, as the proportion of secondary raw materials increased, the water-retention capacity of the mixtures rose from 95.0% for the control composition to 98.0% for Composition No. 11. This can be attributed to the increased specific surface area and porosity of crushed brick, recycled concrete, and limestone filler particles, which are capable of retaining larger amounts of water within the mortar structure.

At the same time, an increase in the secondary component content was accompanied by a gradual decrease in the average density of the hardened material (Fig. 2). The density of the control composition was 1980 kg/m³, whereas that of Composition No. 11 decreased to 1880 kg/m³, corresponding to a reduction of 5.1%. The decrease in density is attributed to the lower density of the recycled aggregates compared with quartz sand and to the increased volume of pore space.

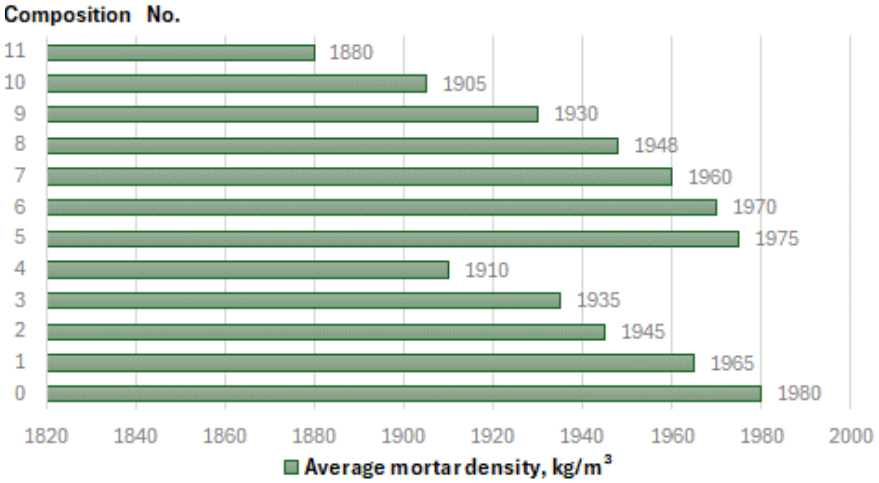


Fig. 2. Variation in the average mortar density depending on mixture composition

The incorporation of moderate amounts of recycled materials has a positive effect on the structure formation of the composite material. The highest compressive strength values were obtained for Compositions Nos. 5 and 6, reaching 29.0 and 29.5 MPa, respectively. Compared with the control composition, the increases in compressive strength were 1.8 and 3.5%, respectively. A similar trend was observed for flexural strength, with maximum values of 6.3-6.4 MPa (Fig. 3).

The increase in strength resulting from the incorporation of an optimal amount of secondary raw materials can be attributed to the microfilling effect and improved particle-size distribution of the mixture [18, 19]. Fine particles obtained from the crushing of construction waste fill the interparticle voids between the cement and quartz sand, thereby promoting the formation of a denser cement matrix.

A further increase in the proportion of secondary components beyond the optimum level results in a gradual decrease in strength. For Composition No. 11, the compressive strength decreases to 24.5 MPa, this is 14.0% lower than that of the control composition. This reduction is attributed to an increase in the water demand of the system and disruption of the optimum binder-to-aggregate ratio.

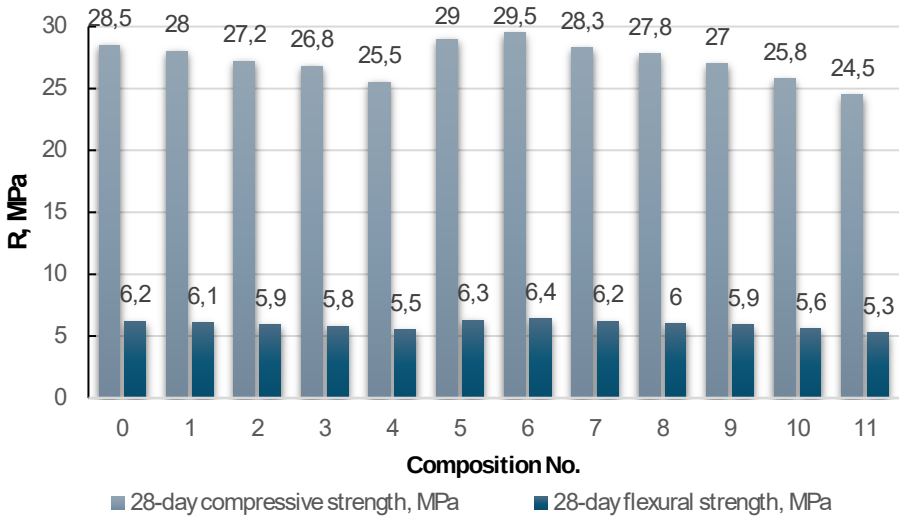


Fig. 3. Variation in mortar strength depending on mixture composition

The adhesion strength of the mortars follows a trend similar to that observed for compressive strength. The maximum value of 0.86 MPa was obtained for Composition No. 6, whereas for Composition No. 11 this parameter decreased to 0.72 MPa (Fig. 4). The results indicate an improvement in the interfacial zone between the cement matrix and the surface of secondary particles when they are incorporated at an optimal content.

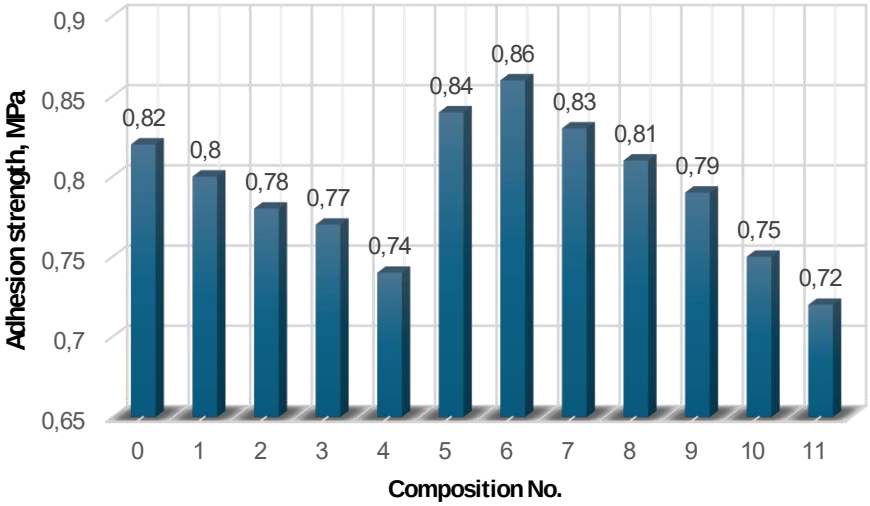


Fig. 4. Variation in mortar adhesion strength depending on mixture composition

Thus, the conducted investigations showed that the incorporation of recycled construction waste products in quantities of up to 20–30% by mass of the mineral fraction of the mixture improves the physical and mechanical properties of the material. Compositions Nos. 5 and 6 proved to be the most effective, achieving the highest compressive strength, flexural strength, and adhesion strength while simultaneously reducing the consumption of conventional aggregate.

To assess the possibility of reducing binder consumption, an additional evaluation of the properties of the optimal Compositions Nos. 5 and 6 was performed by reducing the Portland cement content from 30 to 15%. The content of secondary components remained constant: 25% for Composition No. 5 and 30% for Composition No. 6 (Table 7). The reduction in cement content was compensated for by increasing the proportion of quartz sand.

Table 7 – Physical and mechanical properties of Compositions Nos. 5 and 6 at reduced cement content

Cement content, %	Quartz sand, %	Secondary components, %	Water-retention capacity, %	Average mortar density, kg/m³	28-day compressive strength, MPa	28-day flexural strength, MPa
Composition No. 5						
30.0	45	25	94.8	1975	29.0	6.3
25.0	50	25	94.2	1958	25.8	5.7
20.0	55	25	93.6	1938	21.4	4.8
15.0	60	25	92.8	1915	16.7	3.9
Composition No. 6						
30.0	40	30	94.45	1970	29.5	6.4
25.0	45	30	94.0	1952	26.1	5.8
20.0	50	30	93.4	1932	21.9	4.9
15.0	55	30	92.5	1908	17.3	4.0

The obtained results show that reducing the cement content from 30 to 15% predictably results in a decrease in the physical and mechanical properties of the experimental compositions. For Composition No. 5, the compressive strength decreases from 29.0 to 16.7 MPa, whereas for Composition No. 6 it decreases from 29.5 to 17.3 MPa (Fig. 5). This can be explained by the reduced amount of cement matrix available to bind the quartz sand particles and secondary mineral components into a dense structure.

When the cement content is reduced to 25%, the mixtures retain sufficiently high performance characteristics. The compressive strength is 25.8 MPa for Composition No. 5 and 26.1 MPa for Composition No. 6. At the same time, the adhesion strength decreases to 0.76-0.78 MPa, which remains acceptable for repair, restoration, and plastering mixtures.

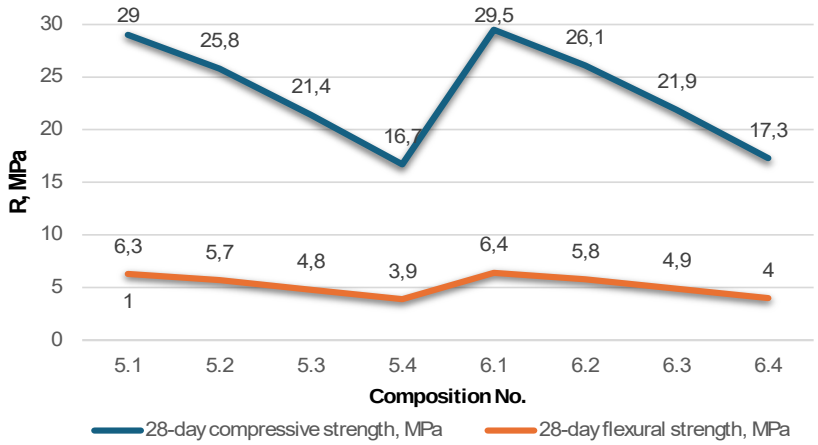


Fig. 5. Variation in the strength of mixture compositions with changes in cement content

A further reduction in cement content to 20% results in a noticeable decrease in strength and adhesion. Such compositions may be recommended primarily for plastering, levelling, or masonry mortars used in structures with relatively low performance requirements [28]. Compositions containing 15% cement exhibit the lowest strength and adhesion values and should therefore be used only for non-load-bearing plastering or auxiliary applications.

Therefore, reducing the cement content from 30 to 25% appears to be the most rational approach, as it provides binder savings while maintaining adequate strength characteristics (Table 8). Composition No. 6 containing 25% cement, 45% quartz sand, and 30% secondary components can be considered optimal in terms of the balance between strength, adhesion, and resource efficiency. Further reduction in binder consumption may be possible through the incorporation of functional additives and mechanical-chemical activation of the mixtures or their individual components.

Table 8 – Comparison of the properties of optimal compositions with regulatory requirements

Property	Requirement of DSTU B V.2.7-126:2011	Control Composition No. 0	Optimal Composition No. 6	Composition No. 6.2 with reduced PC content
Cement content, %	Not specified	30	30	25
Waste content, %	Not specified	0	30	30
Water-retention capacity, %	≥95.0	95.0	94.5	94.0
Average density, kg/m³	Not specified	1980	1970	1952
28-day compressive strength, MPa	≥7.5-15.00*	28.5	29.5	26.1
28-day flexural strength, MPa	≥2.0-4.0*	6.2	6.4	5.8
Adhesion strength, MPa	≥0.5	0.82	0.86	0.78
Frost resistance	F35**	F50-75	F75	F50

*Depending on the class and functional purpose of the dry building mixture.

**Specified only for mixtures intended for exterior applications.

Conclusions:

1. The main approaches to the utilisation of recycled construction waste products in dry building mixture technology for the restoration of buildings and infrastructure have been identified. Recycled concrete, crushed brick, crushed glass, and products derived from limestone crushing were found to be the most promising secondary components, as they can effectively replace part of the natural mineral raw materials.

2. The effect of the secondary component content on the physical and mechanical properties of dry building mixtures was determined experimentally. It was established that increasing the content of recycled materials increases the water-retention capacity of the mixtures from 95.0 to 98.0%, while the average density decreases from 1980 to 1880 kg/m³. At the same time, an excessive increase in the proportion of secondary raw materials leads to a gradual reduction in the strength characteristics of the material.

3. Based on the experimental results, optimal compositions of dry building mixtures were identified. The best performance was achieved by Compositions Nos. 5 and 6, which provided compressive strengths of 29.0 and 29.5 MPa, respectively, flexural strengths of 6.3–6.4 MPa, and adhesion strengths of 0.84–0.86 MPa. Compared with the control composition, compressive strength increased by up to 3.5%, while adhesion strength increased by up to 4.9%.

4. The possibility of reducing cement consumption from 30 to 25% without a significant deterioration in the performance properties of the material was established. For the optimised Composition No. 6, the compressive strength was 26.1 MPa, the flexural strength was 5.8 MPa, and the adhesion strength was 0.78 MPa, which meets the requirements applicable to dry modified building mixtures intended for repair applications.

5. The developed compositions were confirmed to comply with the requirements of DSTU B V.2.7-126:2011 for dry modified building mixtures. The obtained strength and adhesion

characteristics allow these compositions to be recommended for repair and restoration works, the application of levelling layers, the repair of concrete and brick surfaces, and the restoration of elements of residential, public, and infrastructure facilities.

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СУХІ БУДІВЕЛЬНІ СУМІШІ НА ОСНОВІ ПРОДУКТІВ РЕСАЙКЛІНГУ БУДІВЕЛЬНИХ ВІДХОДІВ ДЛЯ ВІДНОВЛЕННЯ ОБ'ЄКТІВ БУДІВНИЦТВА ТА ІНФРАСТРУКТУРИ

[1]**Бондар А.В.**, к.т.н, доцент,
bondarav@vntu.edu.ua, ORCID: 0000-0002-8098-1181
[1]**Кучеренко Л.В.**, к.т.н., доцент,
liliya13liliya13@gmail.com, ORCID: 0000-0003-0348-3610
[2]**Бабій І.М.**, к.т.н., доцент,
igor7617@gmail.com, ORCID: 0000-0001-8650-1751
[1]**Бондар О.В.**, аспірант,
[1]*Вінницький національний технічний університет*
Хмельницьке шосе 95, м. Вінниця, 21021, Україна
[2]*Одеська державна академія будівництва та архітектури*
вул. Дідріхсона, 4, м. Одеса, 65029, Україна

Анотація. У статті досліджено можливості використання продуктів ресайклінгу будівельних відходів у технології сухих будівельних сумішей для потреб відновлення об'єктів будівництва та інфраструктури. Актуальність дослідження обумовлена значними обсягами будівельних відходів, що утворюються внаслідок демонтажу застарілих споруд, реконструкції будівель та руйнувань, спричинених воєнними діями на території України. Раціональне використання вторинної мінеральної сировини є одним із перспективних напрямів забезпечення ресурсозбереження, зниження екологічного навантаження на довкілля та підвищення ефективності післявоєнної відбудови.

Проаналізовано сучасний стан використання продуктів ресайклінгу будівельних відходів у виробництві будівельних матеріалів. Розглянуто можливість застосування заповнювачів із бетонного лому, цегляного бою, склобою та продуктів дроблення вапнякових порід як компонентів сухих будівельних сумішей. Наведено фізико-механічні характеристики вихідних матеріалів та розроблено серію експериментальних складів із різним вмістом вторинних компонентів.

Виконано оцінювання впливу кількості продуктів ресайклінгу на технологічні та експлуатаційні властивості сухих будівельних сумішей. Встановлено, що збільшення частки вторинних компонентів сприяє підвищенню водоутримувальної здатності сумішей та зниженню їх середньої густини. Водночас надмірний вміст вторинної сировини призводить до зменшення міцнісних характеристик матеріалу. За результатами експериментальних досліджень визначено оптимальні склади сумішей, які забезпечують міцність на стиск до 29,5 МПа, міцність на згин до 6,4 МПа та адгезійну міцність до 0,86 МПа.

Досліджено можливість зниження витрати цементу до 25 % в оптимальних складах без суттєвого погіршення експлуатаційних властивостей матеріалу.

Отримані результати підтверджують доцільність застосування розроблених сухих будівельних сумішей для виконання ремонтно-відновлювальних робіт, улаштування вирівнювальних шарів, ремонту бетонних і цегляних поверхонь, а також відновлення елементів житлової, громадської та інженерно-транспортної інфраструктури.

Ключові слова: сухі будівельні суміші, відходи, ресайклінг, ремонтно-відновлювальні роботи, післявоєнна відбудова, технологічні та експлуатаційні властивості, ресурсозбереження, будівельні матеріали.

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