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# PRACTICAL CASES OF RECYCLING SECONDARY GLASS IN BUILDING

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**Abstract.** For Ukraine, the issue of waste management and recycling remains one of the most pressing environmental problems. Glass waste accounts for a significant proportion of the total mass of solid household waste. At the same time, glass does not decompose in natural conditions, which creates a long-term burden on the environment. However, it has the potential to be a promising raw material that can be recycled without losing its basic physical and chemical properties. In this regard, the issue of recycling secondary glass is particularly relevant, especially in the construction industry, which is the main consumer of natural resources (about 50%) and therefore needs to introduce technologies that use alternative raw materials.

This will contribute to reducing the environmental impact, rational use of resources and increasing the economic efficiency of construction. The aim of the work is to determine the effectiveness and feasibility of implementing successful global practices of using recycled glass for the production of building materials in the current conditions of Ukraine.

The analysis of scientific works has revealed the most successful cases of glass recycling for the production of building materials in global practice. The production of asphalt concrete mixtures with the addition of 10 – 30% glass cullet (glasphalt), thermal insulation materials based on foam glass, lightweight concrete with micro-crushed glass as a partial substitute for sand, and finishing materials such as decorative panels and mosaics made of coloured glass chips. In Ukraine, despite the availability of production capacities, the level of glass reuse remains low due to the underdeveloped infrastructure for the collection, sorting and cleaning of glass waste. However, the growing demand for building materials in the post-war reconstruction process creates favourable conditions for scaling up such technologies.

To implement global experience in the use of recycled glass for the production of building materials in Ukraine, the following steps must be taken:

1. Improve the regulatory framework, namely, initiate amendments and develop a series of state building codes and harmonise them with the requirements of the European Committee for Standardisation regarding the use of secondary raw materials in construction.

2. Introduce economic incentives by establishing tax breaks for manufacturers of building materials based on secondary mineral raw materials and giving priority in public procurement to materials containing such raw materials.

3. Create a regional infrastructure for the collection, sorting and processing of recycled glass.

4. Conduct social and informational events.

5. Given the needs of Ukraine's post-war reconstruction, the highest priority is to establish the production of thermal insulation materials (foam glass) to improve the energy efficiency of buildings; develop concrete mixtures based on recycled glass for 3D printing of building structures as an alternative rapid technology for restoring destroyed buildings, and develop materials based on recycled glass for road construction.

**Keywords:** recycled glass; cullet; recycling; construction materials; green construction.

**Introduction**. One of the global challenges of humanity is the intensive accumulation of industrial and solid household waste, a significant part of which is glass. According to international

environmental reports, up to 10% of the total mass of household waste is glass waste. However, the level of their recycling in countries around the world, including Ukraine, remains insufficient.

It is common knowledge that glass practically does not decompose in natural conditions, which creates an ecological threat for our planet. At the same time, It is also worth mentioning that this material has a unique feature – the ability to be recycled without significant loss of its physical and chemical properties with further use, including construction.

Today, one of the key vectors of the development of modern construction is waste minimization and reuse of material resources, as this has not only economic but also environmental advantages. In the conditions of sustainable growth of solid household waste and depletion of natural resources, recycling of secondary glass as an alternative raw material in the production of construction materials is of particular importance.

In addition, the modern technology of glass production from natural raw materials is quite energy-intensive and has a high carbon footprint on the environment. The technological operation of glass making in bath furnaces, namely heating natural raw materials in furnaces to a temperature of 1400 – 1500 °C, accounts for about 75-85% of the total energy requirements for glass production [1–2]. Accordingly, during this process, large amounts of greenhouse gas emissions occur. Therefore, the use of cullet during the production of construction materials will contribute not only to reduce the consumption of natural resources, but also to reduce energy costs and $CO_2$ emissions into the atmosphere.

Despite the significant potential for reuse of glass waste, there are still problems in the practical implementation of glass recycling. They are caused both by technical factors (quality of cleaning, fractionation, etc.) and organizational and economic factors – the lack of state incentives, low level of waste sorting, etc. However, this area is actively developing due to the introduction of new technologies, increased environmental awareness of society and support from European institutions in this area. World experience demonstrates the effectiveness of using recycled glass in the production of concrete, asphalt-concrete mixtures, heat-insulating materials, decorative elements, etc. [3–7].

For Ukraine, the issue of waste management and recycling remains one of the most acute environmental problems. Therefore, international experience in such practices is particularly valuable for our country, especially in the context of post-war reconstruction.

That is why the study of practical cases of recycling recycle glass in construction is an urgent task for scientists and industry specialists. Analysis of successful examples of using glass waste in different countries, comparison of technological solutions and identification of factors ensuring the effectiveness of their implementation will allow to form a basis for the development of a national system of "green" construction. This, in turn, will contribute to reduce the environmental load, rational use of resources and increasing the economic efficiency of construction.

**Analysis of recent research**. The topic of reuse glass waste in construction is being actively studied by both Ukrainian and foreign scientists. Researchers emphasize that recycled glass is an effective alternative raw material for creating environmentally safe, energy-efficient and economically profitable building materials.

Thus, the Ukrainian scientists in their works [8–10] note that the existing glass processing capacities do not correspond to the volumes of its accumulation, while the recycling of construction waste in the context of the reconstruction of Ukraine takes on its significance. The authors emphasize the need to create modern glass processing systems by solving the main problems that hinder this, namely: the lack of legal documents that would regulate the rules for the use of glass waste, shortcomings in the waste collection infrastructure and insufficient involvement of industry. The transition to effective technologies is possible only with the coordination and cooperation of representatives of state policy, science and business in Ukraine.

The most common practices of using recycled glass are: road construction, thermal insulation materials, production of concrete mixtures and decorative trim. The scientists considered in detail [2, 6, 11–14], the effect of introducing recycled glass in the manufacture of various road construction materials, namely asphalt-concrete, base and subbase of road pavement, stabilizing component of soil. First of all, the researches are aimed at selecting the optimal granulometric composition of these materials from recycled glass.

The issue of improving the production technologies of such a thermal insulation material as

foam glass from recycled glass is considered in [15–17], and various finishing materials in [3].

A large number of works [2, 4, 5; 18–20] are devoted to the development of the optimal composition of concretes based on recycled glass, which can be used both as a substitute for the binding component and as a substitute for aggregates for concrete. Of particular interest are the works [21–22], which examine the influence of recycled glass on the rheological properties of concrete mixtures used in the innovative technology of 3D printing of buildings.

**The purpose** of the work is to determine the effectiveness and feasibility of implementing successful world practices of using recycled glass for the production of construction materials in modern Ukrainian conditions.

**Materials and research methods**. The work uses a comprehensive approach, which includes analytical, comparative and generalizing research methods. At the first stage, scientific data on the relevance of glass recycling were collected, at the second stage, a comparative analysis of foreign and Ukrainian experience in the issue of recycling glass was done, successful promising technologies with the highest level of environmental and economic effect were identified. At the third stage, a generalized model of the introduction of glass recycling technologies into the national construction industry was formed, taking into account technical, organizational and social factors.

**Research results**. Recycled glass (cullet) is glass waste that is formed during the production and consumption process and is re-involved in the production cycle. Glass recycling is one of the most developed areas of waste processing. Analysis of scientific works has allowed us to establish that the justification for the use of recycled glass includes several aspects, namely: economic, environmental, technological and, to a lesser extent, design aspects (Fig. 1).

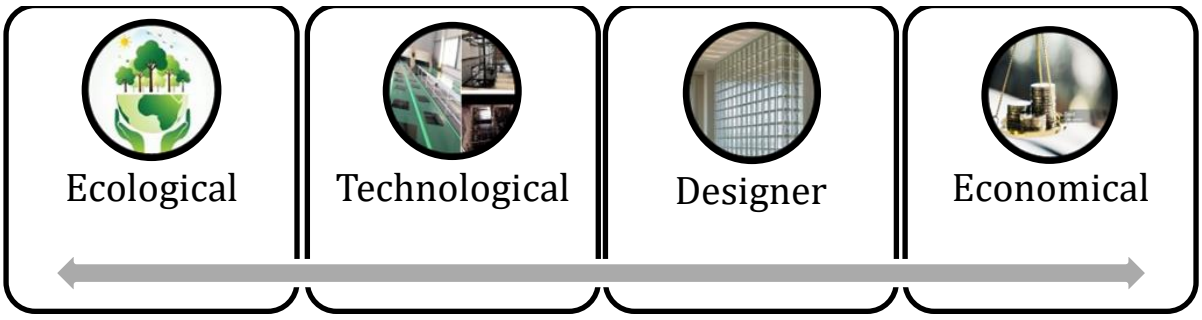


Fig. 1. Key aspects of the feasibility of glass recycling

The economic aspect is to reduce production costs by partially (or completely) replacing primary raw materials with secondary materials. The use of cullet in the production process allows reducing energy costs, reducing time and costs associated with the extraction and transportation of natural resources, thus reducing the cost of finished products. In addition, this process allows creating new workplaces, thus strengthening the country's economy.

In turn, the ecological aspect consists in reducing the amount of waste that ends up in landfills, reducing the ecological load on the environment.

The technological aspect is manifested in the possibility of improving the properties of construction materials by introducing cullet into their composition. With the correct adjustment of the production technology, crushed glass can increase the strength and durability of concrete mixtures, etc.

The design potential of recycled glass opens up new possibilities for architectural and decorative solutions. Due to the variety of colors and textures, cullet is used in the manufacture of mosaics, facade panels, decorative tiles, interior decoration and landscaping elements.

Thus, recycled glass is a multifunctional resource that combines economic feasibility, environmental safety, technological efficiency, and aesthetic appeal, making it an extremely promising raw material for the construction industry.

Modern recycling technologies allow the use of cullet in many areas of the construction industry – from the production of new glass materials (products) to the creation of other construction materials, including decorative ones.

One of such technologies is the use of glass as a raw material. Crushed glass is used in the production of sheet, facade, container glass, as well as fiberglass and glass wool. This allows you to

lower the melting point, reduce energy consumption and the amount of carbon dioxide emissions into the environment, which makes this process ecologicallyy and economically feasible.

Next, we will consider the use of recycled glass in the production of construction thermal insulation materials. Yes, it is the main raw material for the production of foam glass, which is used as a lightweight and fire-resistant insulation in industrial and residential construction. Glass wool is also made from cullet, which is an effective thermal insulation material.

In addition, crushed glass is used in the production of concrete and road surface materials (asphalt concrete, bases and subbases), in which it is usually added as a partial substitute for sand or crushed stone.

The use of cullet also opens new opportunities in ornamental decoration – colored glass chips are added when creating various mosaics, facing slabs, landscape elements, facades, etc.

From the above, we can conclude that the use of recycled glass has a significant number of practical cases in construction. Particular attention should be paid to their use in overseas practice.

Glasphalt (asphalt with glass added) is an asphalt-concrete mixture where part of the filler is replaced with crushed glass. The history of the development of this technology began in the 1970s. Today, it is used in a number of high-tech countries, in particular Japan, Canada, the USA and EU countries. In practice and in scientific research, a number of advantages of using cullet in road construction have been proven, the main of which are the following: reducing the percentage of primary raw material use, recycling of glass waste, reducing cost and improving the properties of asphalt pavement. It should be noted that there is no unified technology and formula for using cullet as alternative filler. Scientists are still working on improving this technology [2, 6, 13–14]. Thus, studies of dynamic behavior have shown that asphalt-concrete containing cullet has better resistance to deformation and higher stiffness modulus [11].

The company RMC Materials, under the Highway Authorities Product Approval Scheme (HAPAS), uses approximately 30% recycled glass in its product, instead of natural aggregates. HAPAS is a British certification scheme that certifies that materials, products and systems used in the construction of highways meet strict requirements for quality, safety and durability. Completing that certification allows the developed material to be used for road construction on all highways, including trunk roads. A three-year HAPAS evaluation scheme confirmed the high effectiveness of the developed Glasphalt compound in operation compared to traditional asphalt from natural crushed stone [12].

Laboratory tests of asphalt-concrete mixtures with the addition of 10-15% cullet (monolithic and tempered glass) have shown that the properties of the mixture change as follows: stiffness decreases, and resistance to permanent deformation decreases. Practice has shown that the content of 10-20% cullet improves wear resistance and roughness of the road surface [6].

A study of Algerian scientists [13] is devoted to the use of recycled glass to grain size correction of pavement unbound granular material (base and subbase). Crushed limestone of the 0–20 mm fraction, which has a deficiency of fine particles, was used as the reference material. The addition of 10% of recycled glass of the 0-0.63 mm fraction significantly improves the granulometric curve of the mixture, fitting it into the regulatory area for the road base. This, in turn, contributes to an increase in the bearing capacity of the material. In addition, a mixture of limestone crushed stone and recycled glass has a filtration coefficient 10 times higher than a mixture of limestone crushed stone and sand. This indicates better drainage and a reduced risk of water accumulation. As a result, this contributes to an increase in the drainage capacity of the road pavement and its durability, even in wet conditions.

Piyush Punetha and Sanjay Shrawan Nimbalkar [14] propose to make the base and subbase of the road surface entirely from recycled materials. It is recommended to combine recycled crushed glass in an amount of 10–30% with recycled concrete aggregate. The article provides a comprehensive assessment of the physical and mechanical properties of secondary aggregates, namely recycled concrete aggregate, crushed brick and crushed glass in the context of flexible road surface construction. It has been proven that road surfaces constructed using aggregates from recycled mineral raw materials have characteristics comparable to those constructed from natural quarry materials. At the same time, they allow to solve the problem of a sharp increase in the amount of construction and demolition waste (the construction and demolition waste or C&D waste for short), the limitation of natural resources and the need for sustainable materials for road construction.

Abderrahim Lakhouit in his work [2] also suggests using crushed recycled glass for soil stabilization, which improves the bearing capacity of the road surface and prevents its erosion. The

laboratory studies have shown that soil mixed with 10-30% glass particles has increased shear strength and reduced settlement, making it a viable alternative for sustainable road construction and foundation materials. At the same time, the author draws attention to the need for scientific research to develop advanced technologies for processing of recycled glass. The diversity of quality and composition of recycled glass can create difficulties when using it as a construction material. Impurities in glass can negatively affect the characteristics of products made from it, which confirms the need to develop advanced technologies for sorting, cleaning and crushing recycled glass. Optimization of these technologies will ensure that recycled glass meets the high standards applicable in the field of construction materials and will help to increase its stability and quality, contributing to its competitiveness with natural materials.

However, there are also certain disadvantages in the use of recycled glass, namely the cost of production, which may be higher. This is due to the fact that to obtain a high-quality final product, such raw materials require preliminary sorting and cleaning, a procedure for assessing the quality of raw materials and the availability of appropriate equipment, infrastructure and logistics. In addition, if the technology for manufacturing asphalt concrete based on recycled glass is not followed, risks may arise during road operation: reduced adhesion of the coating, the need for frequent road repairs, etc.

The next successful case of using recycled glass is the production of foam glass (*foam glass* or *cellular glass*) based on it – an inorganic insulation with a highly porous structure. It is obtained by heating the glass mass to a temperature at which the glass becomes plastic and can foam when a small amount of special gas-forming additives is added, forming closed or partially closed pores. Due to this porous structure, this material has high heat and sound insulation properties, is moisture resistant and durable, which ensures its service life of 100 years or more. Having a number of advantages, such as reducing the total percentage of glass in the mass of waste, reducing the final cost of products, this material becomes attractive in the construction industry.

Thus, in developed countries, foam glass is used as an ecological alternative to insulation, and manufacturing technologies are constantly being improved. A number of scientific studies have provided the advantages of using foam glass in the construction industry. In particular, Horonko et al. in their study [15] claim that foam glass made from recycled glass and perlite has an density of 263 kg/m³, a strength of 2.17 MPa and low thermal conductivity, which allows it to be used as a thermal insulation layer.

The most well-known manufacturers of foam glass in European countries are GLAPOR (Germany) and Misapor (Switzerland). The first mentioned company makes its product from 100% recycled glass [16], while the second notes that its material is successfully used as a filling for floor bases, thus reducing the load on the soil [17].

Another common world practice is the use of recycled glass in the production of various types of concrete. With proper technology for preparing cullet (reduction of fraction, control of reactivity), it is possible to obtain concrete with sufficiently high strength, decorative effect and reduced average density. The first attempts to introduce crushed glass into concrete date back to the 1960s and 1970s, but widespread industrial use began with the advent of glass grinding technology to micropowder in the 21st century. This made it possible to avoid the negative consequences of alkali-silicate reaction (ASR), which previously limited its use in the manufacture of cement materials.

Modern researches show that the selection of the optimal granulometry of crushed glass can significantly increase the strength of concrete. Gengan et al. [4] found that replacing up to 20% of natural aggregate with cullet improves the strength of concrete. The optimal results were obtained at a ratio of 15 – 20%. The same thesis is confirmed in the work of Abderrahim Lakhouit [2], in which, due to the addition of 20% of recycled glass instead of traditional aggregates in concrete, the compressive strength increased by 15%, and carbon emissions decreased by approximately 30%. In addition, the author suggests using finely ground glass powder as an additional cementing material, which will allow reducing the proportion of cement in the composition of concrete. For this, in order to improve the properties of glass powder, it is necessary to carry out chemical or combined activation. The use of processed secondary glass powder in concrete allowed improving its microstructure, reducing porosity, increasing early and final strength, and minimizing the risk of alkali-silica reaction.

In another experiment [5], expanded glass was used as a lightweight aggregate for concretes with a reduced density (1.5–2.2 g/cm³) while obtaining strengths of 18–69 MPa. Such concretes

demonstrate increased thermal insulation and lower weight, which are valuable operational properties of the material for energy-efficient construction.

Lutfar Rahman Rana et al. [18] conducted research on the replacement of fine aggregate in concrete with secondary crushed glass and coarse aggregate with recycled brick aggregate (Recycled brick aggregate concrete or RBAC). It was found that with an increase in the proportion of RBAC, the compressive strength of concrete decreases. This negative effect of RBAC was eliminated and its quality improved by adding 20% secondary glass as fine aggregate.

In the study of Subhan Ahmad et al. [19], the positive effect of recycled crushed glass (RCG) on the quality of concretes in which a proportion of natural coarse aggregate was replaced by recycled coarse aggregate (RCA), in this case made from concrete of a destroyed building. It was found that RCA significantly reduces the mobility of the concrete mixture due to the presence of mortar particles in it, which increase the water absorption of such aggregate, which negatively affects the formation of the concrete structure and its strength characteristics. RCG, which is added to concrete as a substitute for part of the fine aggregate, has a smooth surface and almost does not absorb water, therefore it improves the technological properties of concrete mixtures. The early strength of concretes made with the addition of RCG and RCA at any ratios was lower than that of concretes made from natural aggregates. However, the late strength, namely the 56-day strength of concrete increases in all mixtures made from Recycled aggregates (aggregates from recycled materials). This is explained by the fact that recycled crushed glass densifies the structure of the concrete and promotes the reaction with the silica content in the glass. The best indicators were recorded when 20% RCG was added instead of natural fine aggregate and 50% RCA was added instead of natural coarse aggregate. This composition allowed to obtain a reinforced concrete beam that had a 5% higher shear strength than a beam made from a control concrete mixture without Recycled aggregates.

Also of interest are the studies of Chinese scientists [20] aimed at developing ecological concrete, which is modified with recycled glass powder (Waste glass powder or GP) as an auxiliary cement material, recycled concrete aggregate (Recycled concrete aggregate or RCA) as a coarse aggregate particle and recycled fine brick aggregate (Recycled fine brick aggregate or RFBA) from waste clay bricks as a fine aggregate particle. The following ratio of materials in the concrete mixture is optimal: 15% RCA, 40% RFBA, 10% GP and a water-cement ratio – 0.48. Concrete samples from this composition show the 28-day cube compressive strength at 39.2 MPa, the axial compressive strength at 29.8 MPa and splitting tensile strengtha at 2.72 MPa. These indicators almost meet the design requirements for concrete of class C30/35, only the axial compressive strength instead of the minimum value of 30 MPa has an indicator of 29.8 MPa. Microscopic analysis showed that the C-(A)-S-H gels formed by GP and RFBA reduced the total porosity by approximately 18% and increased the proportion of harmless pores (<20 nm) to 25…28%, which contributed to the improvement of the pore structure. This concrete composition allows for a 10% reduction in cement usage and approximately 50-60% reduction in natural aggregate consumption compared to traditional C30/35 concrete, which directly reduces the risks of land occupation and environmental pollution associated with landfilling.

A research group of scientists in in their studies [21–22] evaluated the feasibility of using recycled glass as a substitute for natural aggregate in concrete mixtures for 3D printing. In both studies, concrete mixtures with recycled glass aggregate demonstrated higher plasticity indices of concrete mixtures compared to traditional mixtures, improving their rheological properties. This is one of the most important characteristics of mixtures used in 3D printing technology, because most modern construction 3D printers usually use the extrusion method, which requires high mobility of the mixtures. However, the mechanical properties of concretes based on recycled glass material were lower compared to concrete based on river sand.

Karla Cuevas et al. in their work [21], in addition to concrete mixtures of heavy concretes for 3D printing, also studied concrete mixtures of light concretes for 3D printing. Lightweight concretes were prepared with 50 and 100% recycled glass aggregate as a substitute for basalt aggregate and with expanded thermoplastic microspheres (ETM) as a pore former. An effective balance between mechanical characteristics and optimal formation of the microstructure of concretes was achieved in lightweight mixtures with the addition of 50% recycled glass and the introduction of ETM. Thus, the results of the research indicate that recycled glass is a more effective substitute for natural aggregates in mixtures for lightweight concretes used for 3D printing of buildings.

Another relevant case is the use of recycled glass as a finishing material to give architectural expressiveness to the premises of buildings. This means the use of recycled glass in interior and exterior products in which cullet can perform two functions – aesthetic (design element due to color, texture, and texture of products) and functional (insulating material or filler) [3]. Such products include facing panels, facade decorative panels, some types of tiles and mosaics, etc.

It is worth mentioning that in European countries and the USA, the use of colored glass cullet in the production of mosaics and decorative facade panels, as well as some exterior and interior elements, is popular. As in other cases, there are both advantages and disadvantages of using cullet for decorative purposes. From a scientific point of view, the advantages include the following: aesthetics (color range, glare, texture, the ability to create mosaics, etc.), physical properties of products – moisture resistance, frost resistance, strength, etc., reduced use of primary raw materials and recycling of glass waste. Problematic issues include: the need to control the quality and purity of cullet (removal of paints, organic impurities), in some cases, increased production costs, insufficiently developed collection infrastructure and logistics, etc.

Canadian-French scientists in their study [23] examined the design and optimization of a network for collecting, sorting and recycling glass waste within a closed supply cycle. The example is a circular network for recycling glass waste, which includes the option of recovering value by crushing and grinding glass, in order to obtain a pozzolanic material that is used as a substitute for the cement fraction in concrete. The authors developed the first integrated mathematical model of a reverse supply chain for cullet, which allows maximizing profits, minimizing $CO_2$ emissions, optimally choosing the locations and sizes of processing facilities, and evaluating different options for reuse and recycling. The model was tested on real data from a waste processing enterprise in the Canadian province of Nova Scotia, on the basis of which practical recommendations were made for promoting sustainable glass recycling practices. According to the results of the scientists, the key influence on the profitability of the system is the optimization of the location and size of glass processing facilities.

Thus, world practice proves that recycled glass can be successfully integrated into various segments of construction – from the production of materials for roads and foundations to the production of interior and facade finishing products. This confirms its versatility and competitiveness as a construction resource. The developed collection infrastructure and established glass processing lines in the countries of Europe and North America are an example of the large-scale implementation of such technologies.

We also note that the prospects of this case are noted by foreign experts. Thus, in the study of Oseng-Rees et al. [3], recycled glass plates were tested in outdoor conditions of bathrooms and kitchens. The material was tested in conditions of high humidity and impacts. At the same time, a significant number of samples remained without visible damage.

One of the significant ecological problems of our country is the accumulation of glass waste. They constitute a significant part of solid household waste, but a small amount of them is sent for recycling. Thus, according to researches of Ukrainian scientists, most glass material ends up in landfills after use, and the underdeveloped system of collection, sorting and logistics does not allow to implement in full the potential of glass recycling.

Even before the start of the full-scale war in Ukraine, several enterprises specialized in collecting and processing recycled glass operated. In particular, the company "Utilita" in Novomoskovsk is implementing a closed cycle of cullet production, namely, it is engaged in collecting, sorting and cleaning cullet using modern European equipment and supplying it directly to glass factories [24], WeDoRe is engaged in a full cycle of processing glass, aluminum and all types of polymers, demonstrating the possibility of transforming waste into a clean semi-finished product that can be used on a par with primary raw materials for further production [25].

The full-scale war had serious consequences in this area – on the one hand, the amount of glass waste has increased, which is associated with a large number of building destructions, and on the other hand, there was a loss of capacity, logistics and investments in specialized companies. Today, the main problems are the lack of collection and sorting infrastructure, insufficient investment in the establishment of the recycling process, and underdeveloped logistics [26].

In Ukraine, the issue of glass recycling for construction purposes is gradually gaining momentum [27, 28], especially in the context of the development of the "green economy" and the

increase in the cost of energy sources. The main directions are the production of thermal insulation materials, use in cement concrete and the creation of decorative solutions. Ukraine is among the countries that have their own production of foam glass (Lviv and Dnipro regions), cement and concrete mixtures with the addition of cullet and decorative materials.

**Conclusions.** The analysis of practical cases of using recycled glass as a raw material for construction materials and products confirmed the economic and environmental feasibility of these technologies. Analysis of world practices showed that the use of cullet in the production of asphalt concrete, concrete mixtures, thermal insulation materials and finishing products, provided that effective technological lines are established, can improve the physical and operational characteristics of these construction materials.

It has been established that there are a number of enterprises operating in our country that use recycled glass to produce various materials, but this number and capacity remain insufficient. Among the reasons are the lack of effective infrastructure for collecting and sorting glass, logistics, a shortage of technological capacities, and the lack of state incentives for the interest of enterprise representatives.

To implement the world experience of using recycled glass for the production of building materials in Ukraine, it is necessary to actualize the following steps:

1. Improve the regulatory framework, namely, to initiate amendments and development of a number of state building codes (SBK) and harmonize them with the requirements of the European Committee for Standardization regarding the use of secondary raw materials in construction.

Ukraine has a general framework for waste management, in particular the Law of Ukraine "On Waste Management", which came into force in 2023, however, for the effective launch of glass waste recycling a number of specialized regulatory documents and technical regulations are not enough. Firstly, it is worth developing a national standard for recycled glass as a construction material, which would clearly define the classification of recycled glass, requirements for its quality (purity, granulometric composition, pozzolanic activity, etc.). Secondly, another effective mechanism is to establish mandatory norms at the legal level regarding the use of a minimum share of recycled mineral raw materials for the production of construction materials, which which are implemented in many countries of the European Union. The possibility of using waste, including recycled glass, is complicated due to the lack of clear criteria between the waste status and the status of construction materials, since waste is subject to a more extensive permitting procedure because of their potential danger to human health. All of this is a significant barrier for large-scale glass recycling in the construction industry.

2. Introduce economic incentives by establishing tax exemptions for producers of construction materials based on recycling mineral raw materials and establishing priority in public procurement for materials containing such raw materials.

3. Create regional infrastructures for collecting, sorting and processing recycled glass. Develop the network of regional centers for collecting, sorting and processing glass within large agglomerations (Kyiv, Dnipro, Odesa, Kharkiv, Lviv) by purchasing modern equipment under the terms of public-private partnership or by involving international investments.

4. Conduct social and informational events. Currently, there is low awareness of the general public about the benefits of separate waste collection and technologically correct solutions for their rational processing, the possibilities and advantages of recycling. Most people consider this idea unattainable in implementation, so it is worth conducting information campaigns with the demonstration and popularization of successful global cases of glass collection, sorting and recycling systems.

In addition, there is a there is a shortage of qualified personnel at both the engineering and labor levels to provide consultations, recommendations, and direct implementation of recycling technologies. The solution of this problem could be the introduction by the Ministry of Education and Science of pilot projects with the opening of centers for sorting and recycling of recycled glass based on specialized universities. Following the example of how energy efficiency centers were opened in several universities of Ukraine. The functioning of such centers will allow to solve several issues at once: the availability of demonstration stands and exhibitions on the usefulness of sorting and recycling of glass; training of specialists in ecology, civil engineering specialties on visual equipment; conducting consultations for communities and scientific research.

5. Taking into account the needs of post-war reconstruction of Ukraine, the highest priority is to establish the production of thermal insulation materials (foam glass) to increase the energy efficiency of buildings; the development of concrete mixtures based on recycled glass for 3D printing

of building structures as an alternative rapid technology for the restoration of destroyed buildings and the development of materials based on recycled glass for road construction.

The implementation of technologies for the use of recycled glass in the production of construction materials in Ukraine is particularly important in view of the European integration movement and the need for transition of the national economy sectors to the principles of a circular economy.

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## ПРАКТИЧНІ КЕЙСИ РЕЦИКЛІНГУ ВТОРИННОГО СКЛА У БУДІВНИЦТВІ

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**Анотація.** Для України питання управління й переробки відходів залишається однією з

найгостріших екологічних проблем. Достатньо значну частку у загальній масі твердих побутових відходів належить саме скляним відходам. При цьому скло практично не розкладається у природних умовах, що створює тривале навантаження на довкілля. Водночас воно має потенціал перспективного сировинного матеріалу, яке може повторно перероблятися без втрати основних фізико-хімічних властивостей. У зв'язку з цим актуальним є питання рециклінгу вторинного скла, особливо у будівельній галузі, яка є головним споживачем природних ресурсів (біля 50 %) і тому, відповідно, потребує запровадження технологій із використанням альтернативних варіантів сировини.

Це сприятиме зниженню екологічного навантаження, раціональному використанню ресурсів і підвищенню економічної ефективності будівництва. Метою роботи є визначення ефективності й можливості імплементації до сучасних умов України успішних світових практик використання вторинного скла для виробництва будівельних матеріалів.

Аналіз наукових робіт дозволив виявити найбільш успішні кейси рециклінгу скла для виробництва будівельних матеріалів у світовій практиці. Виготовлення асфальтобетонних сумішей із додаванням 10 – 30% склобою (glasphalt), теплоізоляційних матеріалів на основі піноскла, легких бетонів із мікроподрібненим склом як частковим замінником піску та оздоблювальних матеріалів, таких як декоративні панелі і мозаїки із кольорової склокрихти. В Україні, попри наявність виробничих потужностей, рівень повторного використання скла залишається низьким через нерозвинену інфраструктуру збирання, сортування та очищення скляних відходів. Проте зростання потреб у будівельних матеріалах у процесі післявоєнного відновлення створює сприятливі умови для масштабування таких технологій.

Для імплементації світового досвіду використання вторинного скла для виробництва будівельних матеріалів в Україні необхідно реалізувати наступні кроки:

1. Покращити нормативно-правову базу, а саме ініціювати внесення змін та розробку низки державних будівельних норм (ДБН) та гармонізувати їх із вимогами European Committee for Standardization щодо використання вторинної сировини у будівництві.

2. Запровадити економічні стимули шляхом встановлення податкових пільг для виробників будівельних матеріалів на основі вторинної мінеральної сировини та встановлення пріоритету у публічних закупівлях на матеріали із вмістом такої сировини.

3. Створити регіональну інфраструктуру збирання, сортування та переробки вторинного скла.

4. Проводити соціально-інформаційні заходи.

5. Враховуючи потреби повоєнної відбудови України найбільш пріоритетним є налагодження виробництва теплоізоляційних матеріалів (піноскла) для підвищення енергоефективності будівель; розробка бетонних сумішей на основі вторинного скла для 3D-друку будівельних конструкцій як альтернативної швидкої технології із відновленню зруйнованих будівель та розробка матеріалів на основі вторинного скла для дорожнього будівництва.

**Ключові слова:** вторинне скло, склобій, рециклінг, будівельні матеріали, «зелене» будівництво.

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