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PROCESSING OF WASTE SHEET GLASS INTO SECONDARY RAW MATERIALS

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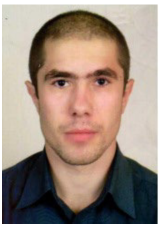

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Abstract

Hundreds of thousands of tons of flat glass waste are generated around the world every year. A huge amount of broken glass resulted from military operations. Recycling construction waste into secondary raw materials is an urgent task, the solution of which will save vast areas of land and natural resources. The purpose of the work is to determine the effectiveness of an innovative technological process for processing construction waste sheet glass into secondary raw materials using small-sized vibration equipment. The research was carried out according to the developed technological scheme, including a vibratory jaw crusher with an inclined crushing chamber, a vibratory dryer, a vibratory screen, and a vibratory mixer. The design features of the laboratory equipment make it possible to install a technological line for processing waste sheet glass at the zero level of the installation site, excluding the use of multi-level metal structures. Taking into account the degree of contamination of flat glass waste and the requirements of production technologies, a limit grain size is established, dividing the crushed product into two classes by size. When processing waste glass according to the developed technological scheme, it is possible to obtain clean glass with a sharp or rounded edge. Laboratory testing of an innovative technological scheme for obtaining secondary raw materials from sheet glass waste using small-sized vibration equipment showed the feasibility and effectiveness of the dry method of processing the source material.

Introduction

Sheet glass is a widely used material based on natural resources, mainly quartz sand, soda ash and limestone. Glass is a durable, inert and brittle material [1, 2], which can be recycled and reused countless times without loss of quality or purity. Currently, the global flat glass market volume is 11.2 billion square meters. According to the forecast of the international analytical company Freedonia, consumption of flat glass will increase by 4.9% annually, reaching 14.3 billion square meters in 2027. An increase in glass production also predetermines an increase in waste, the annual generation of which amounts to hundreds of thousands of tons, but only a small part of it becomes secondary raw materials [3]. Glass waste is a serious environmental problem worldwide [4, 5, 6]. They occupy vast areas of the earth's surface suitable for agricultural and industrial production, and pollute the air, water and soil. Almost without decomposing and retaining sharp chips, cullet is dangerous for animals and people.

Recycling this waste and reusing glass can conserve vast areas of land and natural resources, minimize landfill space and save significant amounts of energy. Producing *1* ton of glass from sand, soda and other materials requires *3* times more energy than using recycled glass. One ton of cullet saves 1.5 tons of mineral glass raw materials, incl. 100-130 kg of soda ash, 40-50 kg of sodium sulfate and 300-350 kg of quartz sand. [7, 8]. In addition, it helps reduce greenhouse gas emissions.

The sources of glass waste are the production process of products at glass factories, municipal solid waste, trimmings during sheet cutting and installation work, modernization, repair and demolition of buildings. A huge amount of glass waste was generated as a result of hostilities. According to calculations of the Kyiv School of Economics, as of the end of 2022, there were more than 150 thousand damaged or destroyed residential buildings in Ukraine [9], and this is hundreds of thousands of tons of glass waste, which it is advisable to process at the site of their generation into secondary raw materials and use them during construction new buildings.

In order to effectively use recycled glass raw materials, a large amount of research is being carried out and the search for new areas of its application is being carried out. One of the most widely used materials in the world is concrete and its constituent cement. Today, annual global cement production has exceeded 3 billion tons and continues to increase [10].

The cement industry is one of the largest industrial sources of greenhouse gas emissions. It has been estimated that each ton of clinker produces one ton of CO_2 [11, 12].

Waste glass and natural sand have approximately the same physical properties, which served as the basis for a possible partial replacement of sand in the production of concrete. Despite the fact that the percentage of glass introduced into the concrete mixture is insignificant, hundreds of thousands of tons of recycled glass raw materials will be used in the overall production of concrete.

Currently, a large amount of research is being carried out on the use of glass waste as aggregate in concrete [13]. One of the research objectives is aimed at determining the rational percentage of glass waste that is acceptable for use as a filler without any impact on the properties of the resulting concrete. In [14], partial replacement of sand with 10%, 15% and 20% was considered. The results confirmed 80% pozzolanic strength activity of the waste glass after 28 days. The flexural strength and compressive strength of the samples containing 20% glass waste were 10.99% and 4.23% higher, respectively, than the control sample after 28 days [15]. Tests using mortar showed that finely ground glass helped reduce expansion by 66% compared to the control mixture. The size of glass waste aggregate particles has a significant impact on the quality of concrete.

Studies were carried out for a wide range of crushed glass grains 0.15-4.75 mm [16, 17], and in [18] it was shown that it is safe to use glass waste with a particle size of 36-50 mm as filler. One of the main uses of glass waste is adding it to the batch of glass melting furnaces. However, in this case, the cullet introduced into the charge must be sorted from foreign impurities, washed, dried and sorted by color in order to match its chemical composition to the composition of the glass being produced. The penetration rate and homogeneity of the glass mass when using glass chips is higher compared to uncrushed glass.

Currently, glass waste is used for the production of fiberglass, foam glass, glass-ceramics and glass-ceramic tiles, characterized by durability, frost and weather resistance, construction and facing bricks, they are used for road construction, as fillers for plastics, rubber, paints and other materials. Currently existing glass processing technologies do not have any noticeable differences; obsolete equipment is used in the form of jaw, rotary, and roller crushers with a low degree of crushing and a multi-stage technological process.

At the same time, in the technological process chain, the crushing and grinding operation is the most expensive due to the consumption of a significant amount of electricity, the high cost of repairs, and the replacement of rapidly wearing crushing elements.

This necessitates the creation of highly efficient small-sized installations that provide a complete technological process for processing minerals, including the preparation of source material, crushing and grinding operations and the separation of a commercial product and indicates the relevance and need for analytical, experimental, design developments aimed at increasing the efficiency of obtaining fine-grained and powder materials directly from glass waste.

Goal of the work. To determine the effectiveness of an innovative technological process for processing construction waste sheet glass into secondary raw materials using small-sized vibration equipment.

Method and materials. The studies were carried out on laboratory samples of the developed innovative equipment according to the technological diagram presented below (Fig. 1).

Glass sorting is the most labor-intensive process; it is done manually and can be performed directly on the site of a destroyed building or at a construction waste site.

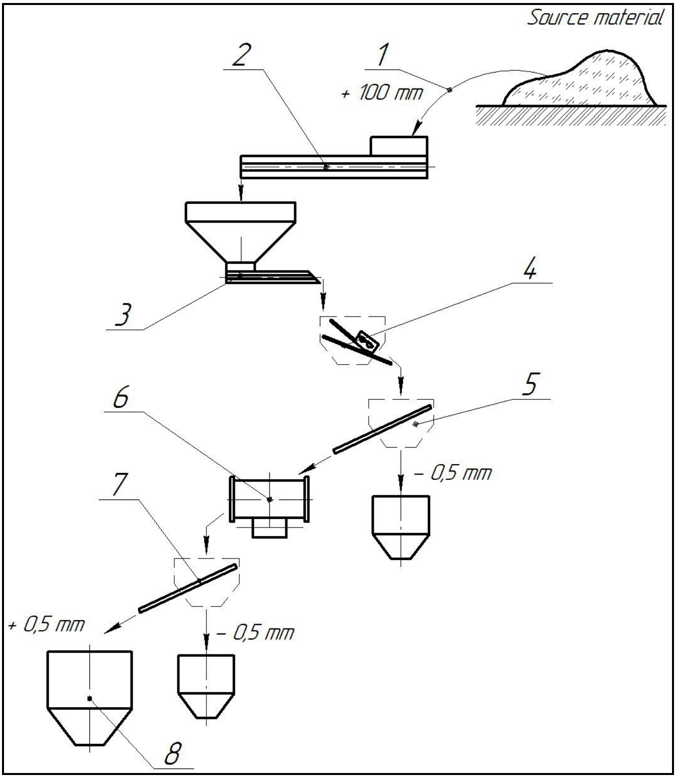

Fig. 1. Circuit diagram of the equipment line for the production of commercial glass chips: *1* - sorting, *2* - vibrating dryer, *3* - feeder, *4* - vibrating crusher, *5* - under-size product hopper, *6* - mixer, *7* - vibrating screen, *8* - secondary raw material hopper

Depending on the degree of destruction of the building [19, 20, 21], the complexity of sorting construction waste is estimated. The least time-consuming and most productive sorting of waste is in buildings of the first category, with up to 40% destroyed (Fig. 2*a*). In the presence of a mobile mobile crushing plant, in most cases, it is possible to dispense with the storage of glass by loading the waste directly into the crusher. Serious difficulties arise during the disassembly of those that have the third category of destroyed (Fig. 2*b*). At the same time, a complete sampling of glass waste is not always possible, a site is required for storage and drying of waste before loading it into the crusher.

a *b*

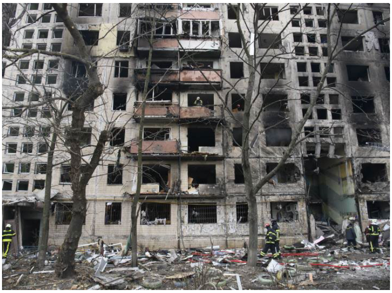

Fig. 2. Destroyed buildings: *a* - minor damage to the enclosing structures; *b* - load-bearing objects that are not suitable for use as intended

Drying can be carried out naturally with the placement of waste under a canopy or with the use of a drying unit. In this study, a laboratory vibro-drying installation of conductive action was considered. The dryer (Fig. 3) contains a vibrating conveyor 1, fixed with the possibility of relative rotation on a heat-insulating frame 2, which rests on supporting elastic elements 3 and is driven into oscillating motion by a vibration exciter 4 of directional action. Shades are installed under the flat working surface 5, which provide heating of the work surface and drying of the material. In fig. 3 the upper cover of the vibrating conveyor, which forms the drying chamber, is conditionally not shown.

If the initial humidity of the glass waste is high, the flat working surface 5 of the vibrating conveyor can be replaced with a perforated one and a convective drying method can be installed. A special feature of the vibration drying unit is the end location of the loading and unloading window, which eliminates the need to install vertical bins and large metal structures.

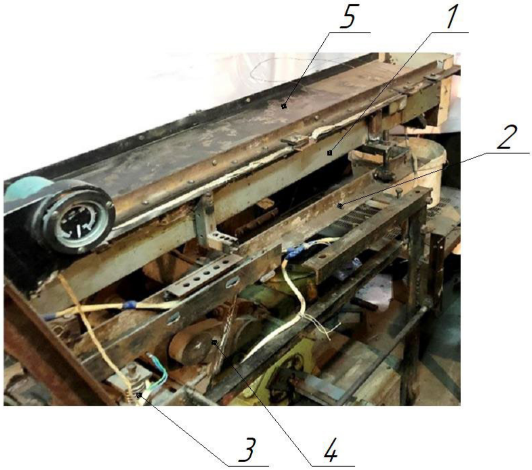

Fig. 3. Vibration drying unit: *1* - vibration conveyor, *2* - thermal insulating frame, *3* - elastic elements, *4* - self-balanced vibration exciter, *5* - working surface

Crushing was carried out on a laboratory sample of a vibrating jaw crusher with an inclined chamber [22]. This type of crusher has a pronounced impact nature of the application of load to the crushed material, and has the advantages of jaw and rotary crushers. Having a large set of adjustable parameters, the process of material destruction is effectively controlled.

In general, the design diagram of the vibratory crusher represents an oscillatory system in which vibrations with a frequency of 16-32 Hz are transmitted to the jaws. The crusher (Fig. 4) includes a passive (lower) crushing jaw *1*, mounted on elastic elements *5* and simultaneously serving as a housing.

The active jaw *3* is installed in the racks of the passive jaw by means of the suspension axis *2*, relative to which it can perform rotational oscillations. The vibrations of the jaws are generated by a two-shaft inertial vibration exciter *4*. The destruction of the material occurs in the crushing chamber formed by the working surfaces of the passive *1* and active *3* jaws. The design feature of the crusher allows loading of the source material and unloading of the crushed product in a horizontal plane, which is especially important when processing sheet material.

a *b*

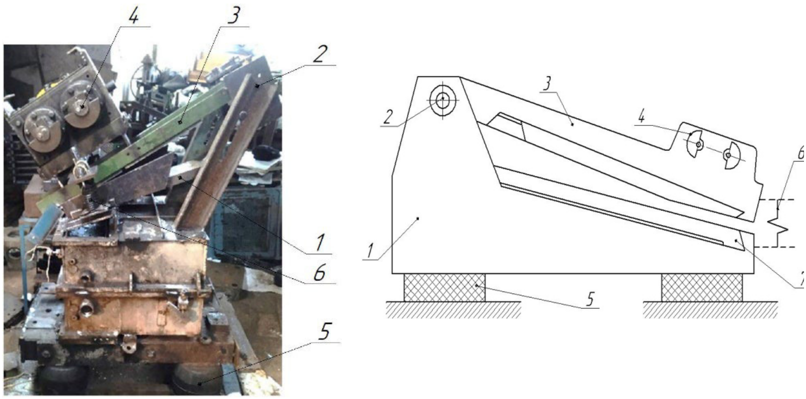

Fig. 4. Vibrating jaw crusher with an inclined chamber: *a* – general view of the crusher, *b* – structural diagram: *1* - passive jaw; *2* - suspension axis; *3* - active jaw; *4* - vibration exciter; *5* - elastic elements; *6* - elastic element; *7* - lining

Technical characteristics of the crusher

Dimensions of the receiving window, mm	130×100
Height of unloading slot, mm	0-50
Crushing chamber length, mm	500
Angle of inclination of the lower jaw, Rad	0-0.9
Jaw vibration frequency, Hz	0-25
Dimensions, mm	
length	1000
width	600
height	1200

The technical characteristics of the crusher, as the main unit of the technological chain, are the basis for determining the parameters of related equipment. Separation of crushed material was carried out on a screen with end docking windows.

The source material was sorted from a construction waste dump and is 4 mm thick sheet glass. Taking into account the width of the crushing chamber of a laboratory sample of a vibrating jaw crusher, following the destruction of glass on a impactor, pieces (Fig. 5) with a particle size of 100-130 mm were selected

Fig. 5. Primary state of glass waste

The broken glass has a sharp chip, the flat surface is covered with mud and paint in places, the edges contain putty residues. In the process of crushing the material, the vibration frequency of the cheeks was 16.7 Hz, the width of the unloading gap in a stationary position was taken to be 0 mm and 10 mm. Such limiting values of the slot width are taken from the condition of assessing the influence of one of the crusher control parameters on the particle size distribution of the crushed product.

A qualitative picture of the surface of crushed glass (Fig. 6*a*,*b*) shows different densities of grains, depending on the width of the unloading slot. On the surface there are dark grains of the broken mud component of the original material.

a *b*

Fig. 6. Crushed waste sheet glass at the discharge slot: *a* – 10 mm; *b* – 0 mm

Some manufacturing processes do not allow sharp chipping of glass chips. In this regard, a vibrating mixer was introduced into the technological chain under study. The qualitative picture (Fig. 6*a*,*b*) of the results obtained shows a high degree of roundness (Fig. 6*b*) and the feasibility of using a vibrating mixer to change the surface shape of crushed glass

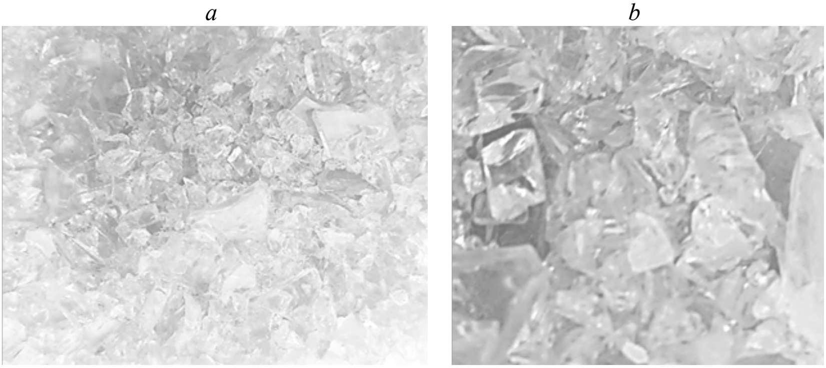

Fig. 7. Shape of the end surface of the glass: *a* – sharp chip; *b* – rounded chip

The crushed material on a vibrating screen was separated into a size of 0.56 mm, corresponding to one of the standard size classes of graded sand.

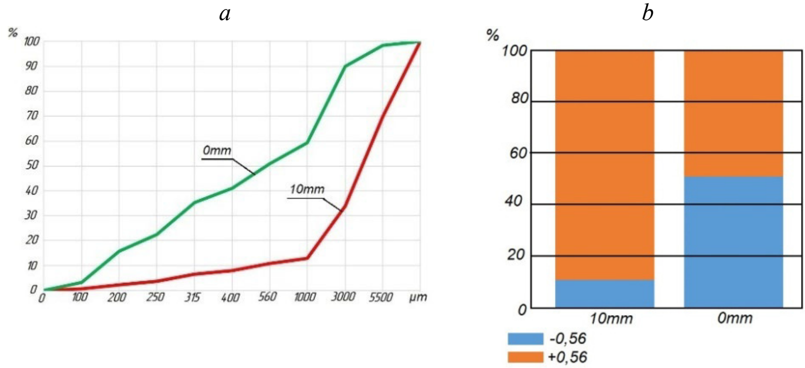

Fig. 8. Characteristics of crushed glass size: *a* – graphical dependence; *b* – diagram

As can be seen from the graphical dependence (Fig. 8*a*), the width of the unloading slot significantly affects the granulometric composition of the crushed material, which shows the possibility of changing the content of the required size class in the finished product. If we take the size of the finished secondary raw material +0.56 mm (based on production or other requirements), its percentage content differs by 5 times.

Conclusions

1. Laboratory testing of an innovative technological scheme for obtaining secondary raw materials from sheet glass waste using small-sized vibration equipment showed the feasibility and effectiveness of the dry method of processing the source material.

2. The limiting grain size dividing the crushed product into two classes by size is taken into account the degree of contamination of flat glass waste and the requirements of production technologies.

3. The design features of the tested laboratory equipment make it possible to install a technological line for processing waste sheet glass at zero level of the installation site, excluding the use of multilevel metal structures.

4. The technological capabilities of the tested laboratory equipment make it possible to obtain clean glass with a sharp or rounded edge.

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