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Innovative technology and equipment for stone processing sludge recycling

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Abstract. The aim of the study is to substantiate the parameters of technology and equipment for the manufacture of building products using alumina sludge from stone processing as an alumina aggregate. The standard methods of setting up an experiment for laboratory washing of granular sludge from stone processing and studying its physical and mechanical characteristics, manufacturing laboratory samples of polystyrene concrete blocks with further study of their strength characteristics were used. The physical and mechanical characteristics of granular man-made material - sludge waste from the stone processing industry - were experimentally determined. The possibility of using man-made sludge in the manufacture of polystyrene concrete blocks was substantiated by its particle size distribution and mineralogical composition. Average samples of granular material were deslagged using the TurboWash unit. The particle size distribution of the material after washing was analysed. According to the standard technology, recipe and raw materials for D300 polystyrene concrete, polystyrene concrete blocks of standard sizes of three grades were produced. Primary sludge without preliminary processing, sand and dusty loess obtained from the processing of primary sludge were used as an aggregate. The numerical values of the axial compression resistance for the studied grades of polystyrene concrete blocks were determined.

1. Introduction

The technology for the production of decorative stone products usually involves sawing blocks with the predominant use of linear, band, disk and rope saws. At the next stages of processing, powder-coated tools, fabric and felt wheels, and chromium oxide paste are used to polish the surface of the stone. A circulating process water supply is used to cool the stone processing tools and remove sand and dust. This traditional stone processing technology leads to the generation of a significant amount of waste, which is a sludge in the form of a mixture of sand and fine dust. Relatively large waste requires disintegration for further utilization using both traditional and new technologies [1-4]. Every year, the industry of Zhytomyr region alone needs to utilize more than 50,000 m^3 of sludge [5-7]. At the same time, sludge is usually uncontrollably discharged into the environment, which leads to significant pollution of the territories and disruption of the ecological balance [5-7]. To prevent such an impact on the environment, at the request of the Zhytomyr Regional State Administration, specialists of Dnipro University of Technology performed scientific and technical work and developed "Conceptual technological solutions for the site for the collection and primary recycling of waste from stone processing enterprises in the Korostyshiv district of Zhytomyr region" [8]. Later, a working draft was developed and a patent was obtained for a method of sludge processing [9, 10]. In order to further

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developments a waste-free technology of stone processing waste [6, 11], it was first proposed to use such waste as alumina aggregate in the production of building products. The use of alumina aggregates from mining waste is of interest to the industry, but requires an individual approach to each type of raw material [12, 13]. In this regard, the development of technology for the utilization of specific industrial waste, especially through the production of marketable products, is an urgent scientific and technical task.

Thus, the aim of the work is to substantiate the parameters of technology and equipment for the manufacture of building products using a stone processing sludge as alumina aggregate.

2. Methods

The study was accompanied by the use of standard methods for setting up an experiment [14-17] during the gravity processing of granular sludge from stone processing and further study of its physical and mechanical characteristics, the manufacture of laboratory samples of polystyrene concrete blocks of standard sizes, followed by the determination of experimental values of resistance to axial compression using specialized press equipment. The study was conducted in the following logical sequence: studying the physical and mechanical characteristics of several portions of the initial sludge; laboratory gravity washing of sludge using the TurboWash unit; determination and analysis of the granulometric composition and basic physical and mechanical parameters of granular materials obtained from the results of washing; production of a sufficient number of polystyrene concrete blocks of standard sizes according to standard recipes; studying their strength characteristics using specialized equipment.

3. Results and discussion

3.1. Study of primary sludge characteristics

For laboratory research, 4 portions of waste produced by stone processing enterprises in the Zhytomyr region were presented, which differ significantly in their characteristics, namely in granulometric composition. According to the results of laboratory studies [18], the particle size distribution and mineralogical composition of primary sludge were determined (table 1).

Table 1. Granulometric composition of sludge.

Size, mm	Portion 1 *yield*, %	Portion 2 *yield*, %	Portion 3 *yield*, %	Size, mm	Portion 4[a] *yield*, %
more 5	0	0	0	more 5	0
from 5 to 2.5	1.50	0.50	1.00	from 5 to 2.5	0.04
from 2.5 to 1.25	1.50	0.50	1.50	from 2.5 to 1.8	0.14
				from 1.8 to 1	0.19
from 1.25 to 0.63	8.00	4.50	6.50	from 1 to 0.63	2.32
				from 0.63 to 0.5	2.84
from 0.63 to 0.315	12.50	28.00	13.50	from 0.5 to 0.4	2.69
				from 0.4 to 0.315	4.35
from 0.315 to 0.16	34.00	37.50	48.00	from 0.315 to 0.2	7.19
				from 0.2 to 0.16	8.76
				from 0.16 to 0.1	9.92
less 0.16	42.50	29.00	29.50	from 0.1 to 0.05	34.13
				less 0.05	27.42
Sum	100.00	100.00	100.00		100.00
Average diameter d_{av}, mm	0.37	0.34	0.35		0.156
Bulk density, kg/m^3	1110	1340	1160		1546
Mineral density, kg/m^3	2.89	2.85	2.91		not determined
Size module	0.965	1.11	1.06		0.123

[a] The granulometric composition of portions 1-3 was determined by the customer after separation of the dust part, the granulometric composition of portion 4 was determined by the authors without prior separation of the dust part.

In terms of mineralogical composition, the sludge contains feldspars, potassium (microclines) and sodium albites, with small amounts of quartz and mica.

In portion 4, which is of the greatest interest for further work on the development of its processing technology, the average sludge size is 0.15 mm, bulk density – 1546 kg/m^3. Content of grains that have passed through the sieves 0.16, 0.1, 0.05 mm correspond to – 71.48, 61.55, 27.42 % by weight.

According to the revealed mineralogical composition, according to "DSTU B V.2.7-45:2010, cellular concrete. General technical conditions" [14, 19] sludge after appropriate preliminary processing can be used for the production of construction sands and as alumina aggregates for cellular concrete in the production of construction products, such as polystyrene concrete blocks. According to the granulometric composition (tables 1, 2), construction sand can be obtained from sludge using hydraulic processing technologies that can technologically and economically remove dusty and fine impurities [20-24]. Given the significant number of such inclusions, it is rational to use the technology of multi-stage gravity classification, which consists in the alternate and sequential use of vertical and horizontal accelerated flows of the carrier flow for gravitational separation of solid particles by size and density. The technology is implemented in the innovative TurboWash unit.

3.2. Laboratory tests of sludge washing

For laboratory studies on the washing of the provided sludge, a laboratory unit TurboWash was used, consisting of a water supply system, a jet feeder, a hydraulic horizontal classifier [18]. In addition, the following standard equipment was used to perform the necessary measurements:

1. Precision pressure gauge with a measuring discreteness of 0.005 kgf/cm^2 (accuracy class 0,6).
2. Laboratory cylinder with a volume of 1 liter with a discreteness of 2 ml.
3. Stopwatch "Agate" with a resolution of 0.5 s.
4. Scales VL-600 with a resolution of 0.01 g, VNC-2 with a resolution of 2 g, TU 25-06-2068-82, RN-10C13M with a resolution of 5 g, GOST 7327-55.
5. Laboratory metal fabric sieves SL-200 TU U 28.7-2210200135-002:2007 with mesh sizes 0.05, 0.1, 0.16, 0.2, 0.315, 0.4, 0.5, 0.63, 1.0, 1.8, 2.5, 5.0 mm.
6. Laboratory vibration sieve analyzer ASV-200, OJSC "NPK "Mechanobr-technica".
7. Drying cabinet.

Laboratory studies of the process of gravity sludge washing using the TurboWash unit [18] were carried out in the following sequence. Opened the mains valve and the water supply system control valve, supplied water to the irrigation comb of the jet feeder and the jet pump. The pressure in the water supply system was monitored by pressure gauges and maintained at the set position. Filled the flow cavities of the classifier and connecting pipes with water. Full filling was controlled by the presence of water drainage from the classifier. A portion of the control granular material (primary sludge) was poured into the feeder and fed through the control hole in a distributed flow to the receiving hopper of the jet feeder. The slurry prepared with the help of an irrigation comb was fed by a jet pump to the inlet of the classifier. Performed visual observation of the process of classification of granular material in an accelerated horizontal flow and its deposition in a hopper. The slurry yield was determined by the volumetric method. The obtained values were recorded in the research journal. The classification process was stopped after the completion of slurry feeding by the jet feeder. Water supply to the irrigation comb and jet pump was stopped.

The experiment cycle was completed after removing the granular material from the sand hopper. After drying in a drying cabinet, the material was divided into classes. For this purpose, laboratory metal fabric sieves SL-200 with mesh sizes of 0.05, 0.1, 0.16, 0.2, 0.315, 0.4, 0.5, 0.63, 1.0, 1.8, 2.5, 5.0 mm were used. The data obtained were recorded in a research journal.

In the course of laboratory tests on sludge washing, two average compositions of granular material were washed. The first included the source material, consisting of the first, second and third portions of sludge. The second composition included the input material made up of the fourth portion of sludge.

The granulometric composition of the granular material obtained after washing both sludge

compositions at the TurboWash plant is shown in the tables 2, 3. Graphical analysis of the size of primary and washed sludge is shown in the following figures 1, 2.

Table 2. Granulometric composition of the granular material after washing the first sludge composition at the TurboWash plant.

Size, mm	Washed sludge		
	mass, g	*yield*, %	*cumulative class yield*, %
more 5	0.00	0.00	0.00
from 5 to 2.5	0.00	0.00	0.00
from 2.5 to 1.8	2.00	0.67	0.67
from 1.8 to 1	9.00	3.01	3.68
from 1 to 0.63	40.00	13.38	17.06
from 0.63 to 0.5	34.00	11.37	28.43
from 0.5 to 0.4	38.00	12.71	41.14
from 0.4 to 0.315	51.00	17.06	58.19
from 0.315 to 0.2	70.00	23.41	81.61
from 0.2 to 0.16	24.00	8.03	89.63
from 0.16 to 0.1	15.00	5.02	94.65
from 0.1 to 0.05	16.00	5.35	100.00
less 0.05	0.00	0.00	100.00
Sum	299	100	d_{av}=0.43 mm

Table 3. Granulometric composition of the granular material after washing the second sludge composition at the TurboWash plant.

Size, mm	Washed sludge		
	mass, g	yield, %	cumulative class yield, %
more 5	0.00	0.00	0.00
from 5 to 2.5	0.00	0.00	0.00
from 2.5 to 1.8	0.53	0.18	0.18
from 1.8 to 1	2.03	0.68	0.86
from 1 to 0.63	34.05	11.37	12.23
from 0.63 to 0.5	36.89	12.32	24.55
from 0.5 to 0.4	31.97	10.68	35.23
from 0.4 to 0.315	42.33	14.14	49.37
from 0.315 to 0.2	41.96	14.01	63.38
from 0.2 to 0.16	22.72	7.59	70.97
from 0.16 to 0.1	16.34	5.46	76.43
from 0.1 to 0.05	29.57	9.88	86.30
less 0.05	41.01	13.70	100.00
Sum	299.40	100.00	d_{av} =0.34 mm

Figure 1 shows a graphical analysis of the particle size distribution of the sludge of the first, second and third portions and the granular material obtained as a result of their washing at the TurboWash laboratory unit. The graphs show that after washing, the grain material became larger. For example, if the percentage of sand larger than 0.16 mm in the sludge of the first, second and third portions was 57.5, 71.0, 70.5 %, respectively, then after washing it was 89.63 %. This affected the value of the average grain size, which after washing amounted to 0.43 mm. The bulk density was 1386 kg/m^3. The content of grains that passed through the 0.16 and 0.1 mm sieves was 10.37 and 5.35 % by

weight, respectively. The content of dusty grains that passed through a 0.05 mm sieve was not detected.

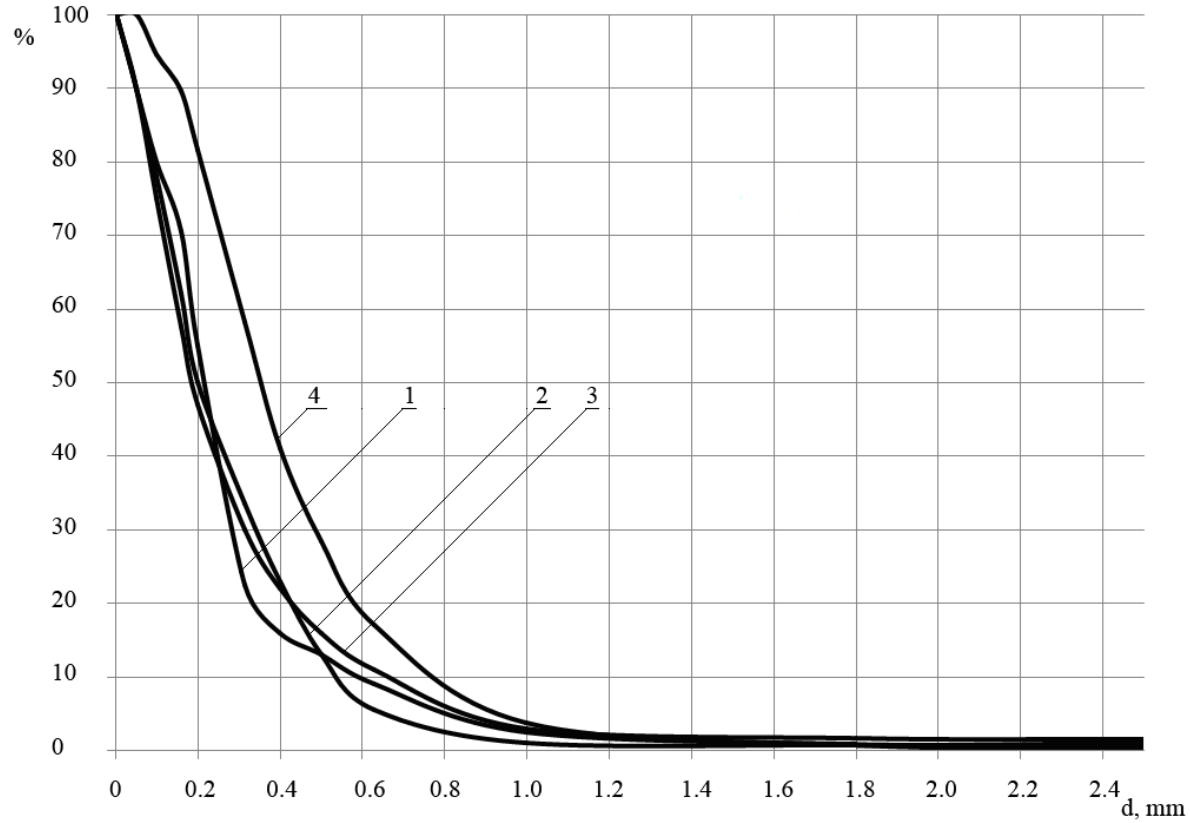


Figure 1. Particle size distribution of sludges from the first 1, second 2 and third 3 portions and those washed in the laboratory unit TurboWash 4.

Figure 2 shows a graphical analysis of the particle size distribution of sludge of the second composition (fourth portion) and granular material obtained as a result of their washing at the TurboWash laboratory unit. The graphs show that after washing, the grain material became larger. For example, if the percentage of sand larger than 0.1 mm in the primary sludge was 38.5%, after washing it was 76.4%. This affected the value of the average grain size, which was 0.15 mm in the sludge of the second composition (fourth portion), and after washing it was 0.34 mm. The bulk density was 1456 kg/m^3. The content of grains that passed through the sieves of 0.16, 0.1, 0.05 mm was 29.0, 23.6, 13.7% by weight, respectively. This result, obtained after a single washing, indicates the need for repeated washing to completely remove grains smaller than 0.05 mm from the finished product. The bulk density of the class of granular material less than 0.1 mm was 1597 kg /m^3.

3.3. Production of laboratory samples of polystyrene concrete blocks

The production of polystyrene concrete blocks in the laboratory is carried out using equipment and utensils as part of: metal container, volume 30 liters; drill "Proton DZ-750"; mixer; capacity for block formation 300x200x300 mm, laboratory spatula. Quantitative measurements of the ingredients of the mixture were performed using the following devices: scales VL-600 with a resolution of 0.01 g, scales VNC-2 with a resolution of 2 g, TU 25-06-2068-82, scales PH-10C13M with a resolution of 5 g, GOST 7327-55; laboratory cylinder with a volume of 0.2 liters with a resolution of 1 ml. The climatic conditions in the manufacture of the blocks corresponded to the following indicators: ambient temperature +31 °C; air humidity 47%; atmospheric pressure 749 mm Hg.

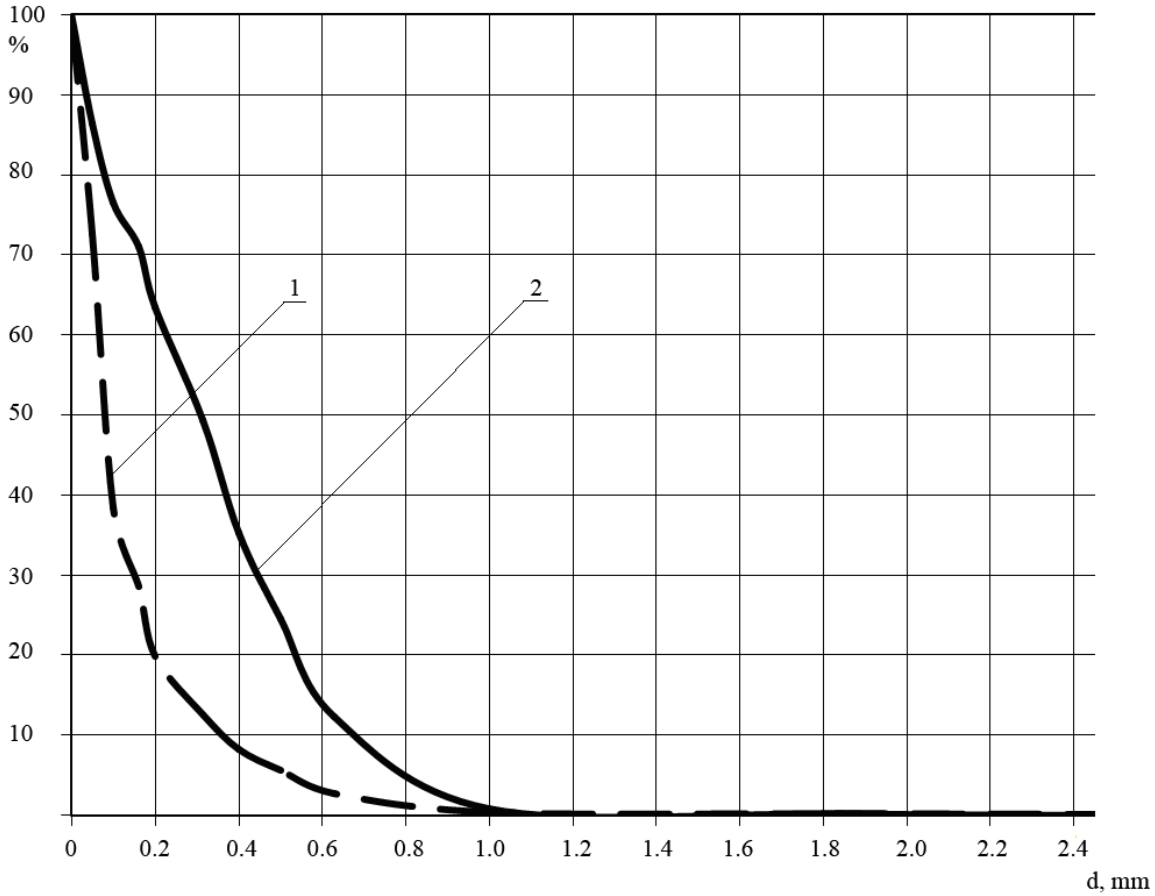


Figure 2. Granulometric composition of primary sludge from the fourth portion 1 and washed at the laboratory unit TurboWash 2.

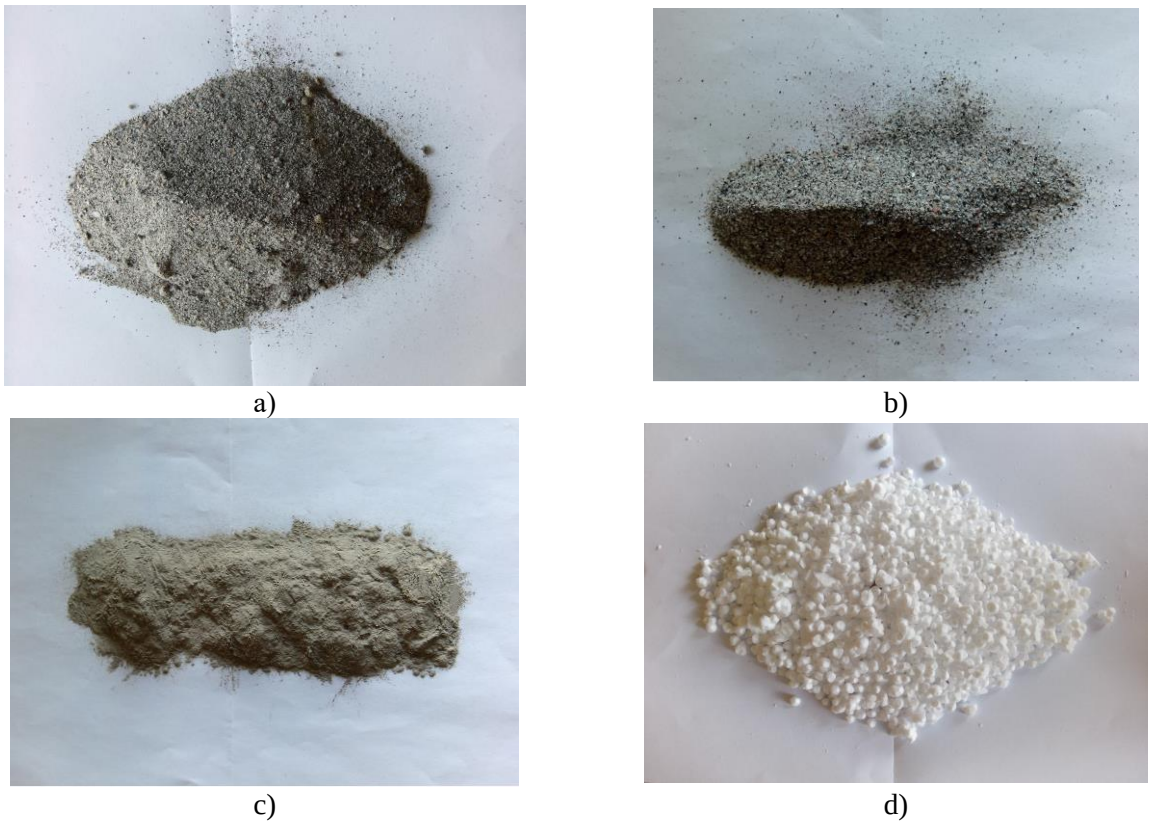
The following materials were used as ingredients in the manufacture of polystyrene concrete blocks:

- primary sludge (figure 3, a);
- de-sludged granular material obtained as a result of washing the first composition of primary sludge at the TurboWash laboratory plant (figure 3, b);
- dusty class with a particle size of less than 0.1 mm obtained from primary sludge (figure 3, c);
- cement: "Portland cement" grade 500, DSTU B V.2.7-46:2010 produced by PJSC Ivano-Frankivskcement [25];
- filler GPS-M-15 lightweight polystyrene TU U 22.2-34556343-003:2014 manufactured by LLC "Trading House "Mliyivsky ZTO" (figure 3, d);
- drinking water: "DSTU 7525:2014 Drinking water. Requirements and methods of quality control";

Fairy detergent: Fairy detergent: "DSTU 2665:2012 Synthetic detergents. Method for determination of detergent ability" [26].

In the laboratory production of polystyrene concrete blocks, the technology and recipe were used, which roughly correspond to the D300 brand [27-30]. The laboratory production of polystyrene concrete blocks was carried out in the following sequence. 4 kg of water (27.99993 %) was poured into a metal container 3, 10 ml of Fairy detergent (0.00007 %) was added and mixed with a drill 1 and a mixer 2 for 1 minute until a stable foam was formed (figure 4). To the resulting mixture was added 6.9 kg of cement (48.1%) and 3.2 kg of granular material (22,2 %). Depending on the type of polystyrene concrete block, primary sludge was used (figure, a), the grain material de-sludged in the laboratory TurboWash plant (figure 3, b), dusty class with a particle size of less than 0.1 mm

(figure 3, c). The resulting mixture was mixed with a mixer for 4 minutes until a homogeneous mass was obtained.



a) b) c) d)

Figure 3. Ingredients used in the manufacture of polystyrene concrete blocks: sludge a, de-sludged granular material at the TurboWash laboratory plant b; dusty class with a particle size of less than 0.1 mm c; GPS-M-15 lightweight polystyrene filler d.



a) b)

Figure 4. Equipment for laboratory production of polystyrene concrete blocks: a – design scheme; b – laboratory equipment.

To the resulting mixture was gradually added 0.25 kg of lightweight polystyrene filler GPS-M-15 (1.7 %) (figure 3, d) with constant stirring for 8 minutes, until the granules are completely wetted and a homogeneous solution is obtained (figure 5, a). The finished solution was transferred to the mold with a spatula and periodically tamped to avoid the formation of voids in the finished product (figure 5, b).



a) b)

Figure 5. Production of laboratory samples of polystyrene concrete blocks:
a – mixing in a container; b – block formation.

The data on the preparation of laboratory samples of polystyrene concrete blocks were recorded in a journal. 10 hours after the block was molded, it was removed from the mold and dried naturally for 2 weeks until it was completely dry.

As mentioned above, the technology and recipe used in the manufacture of polystyrene concrete blocks are roughly the same as for D300 [27-30]. To select the starting materials and justify the production technology, it is necessary to determine the strength characteristics of the manufactured polystyrene concrete blocks. At this stage of development, the main strength parameter was determined, namely the value of resistance to axial compression (prismatic strength). To determine the numerical value of the resistance to axial compression, polystyrene concrete blocks with dimensions of 100x100x100 mm were obtained by sawing (figure 6).

The numerical value of the axial compression resistance was determined using a specialized press model KL200/CE manufactured by Tecnotest (Italy).



a) b) c)

Figure 6. Polystyrene concrete blocks measuring 100x100x100 mm, made using: a) sludge of the first composition; b) dusty class less 100 microns; c) washed and de-slagged sand.

The results of determining the numerical value of the resistance to axial compression are shown in table 4. Under the numbers are encrypted blocks made using: 1 – sludge of the first composition; 2 – dusty class less 100 microns; 3 – washed and de-slagged sand. According to the obtained values of resistance to axial compression, the maximum values were obtained for blocks made using sludge of the first composition and dusty class - 100 microns.

Table 4. Experimental numerical values of resistance at axial compression, MPa.

Number of the experiment	Number of the block		
	1	2	3
1	0.76	1.14	0.41
2	0.61	0.9	0.48
3	1.04	0.98	0.34
4	0.95	1.16	0.38
The average value	0.84	1.04	0.4

3.4. Technology of stone processing sludge recycling

Taking into account the data obtained from the processing of granular sludge and the manufacture of polystyrene cjncrete blocks, the technology for the stone processing sludge recycling with the subsequent manufacture of building products can consist of the following sequential processes. After the sludge is delivered to a specialized landfill, the granular material is pre-processed by sorting by size, classifying it in a water environment, and accumulating the resulting recyclables and tailings in sumps and open storage facilities. In general, the technology for the sludge recycling is proposed in the following sequence. The primary sludge is removed from the warehouse using wheel loaders and delivered to the processing area, where it is divided into separate classes by size using a sludge classification module in a water environment. After processing and washing, the sandy class is transported and stored in a temporary secondary mineral raw material warehouse, and the fine grades in the slurry are drained into a storage tank. After siltation of the storage tank, it is cleaned with the storage of fine raw materials to the temporary storage of secondary mineral raw materials. When processing and classifying sludge in a water environment, a recycling water supply system is used, while a system for feeding the processing process with technologically clean water is used to compensate for process water losses. The resulting mineral raw materials are then used as bulk material and as alumina aggregate for the manufacture of construction products.

4. Conclusions

Taking into account the results obtained in the course of laboratory studies, it is rational and technologically feasible to recycle stone processing sludge to obtain construction sands, while fine and dusty classes with a size of less than 100 microns should be used in the production of cellular concrete, for example polystyrene concrete blocks.

The use of the TurboWash laboratory unit allows to significantly change the granulometric composition of the granular material. The percentage of sand larger than 0.1 mm after a single washing was 76.4 % compared to 38.5 % in the primary sludge, the average grain size of the fourth portion was 0.34 mm and 0.15 mm, respectively. To completely remove grains smaller than 0.05 mm from the finished product, a second rinse is required.

The results of experimental studies of the compressive strength of samples of polystyrene concrete blocks show that the use of fine and dusty classes with a particle size of less than 100 microns as a agregates provides strength 19 % higher than the strength of blocks with agregates in the form of primary sludge, and 62 % higher than the strength of blocks with agregates in the form of washed, de-sludged sand.

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primary processing of waste from stone processing enterprises in the Korostyshiv district of Zhytomyr region".

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