Application of surface wastewater sludge in the production of composite building materials

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Abstract. The article deals with the efficient disposal of technogenic waste, wastewater sludge in particular. On the basis of literary sources the possible uses of wastewater sediment in the production of building materials are considered. The proposed option is to organize materials using sediments of wastewater, which is based on the dependence of the aggregate condition of sediment on the type of building material. It is suggested to use wastewater sludge as complex additive to improve the rheological characteristics at all stages of hardening of cement-sand and concrete mixtures, as well as to improve the physical and mechanical properties of cement-sand samples. The physical (material) and chemical composition of sediment has been studied, their physical and mechanical characteristics have been determined. In order to determine the effect of introducing sewage sludge modified with plasticizing additives into the concrete composition on compressive strength and average density a single-factor variance analysis was carried out. The optimal percentage of sewage sludge in the composition of heavy concrete was selected, as well as the optimal ratio of chemical modifying additives.

1. Introduction
Currently, one of the main environmental problems of large cities is the contamination of urban reservoirs with surface wastewater. Surface runoff from the territory of the city is one of the strongest sources of water pollution with various impurities of natural and man-made origin. Russian legislation prohibits dumping surface wastewater that is not treated to the established standards into water bodies [1-3]. Processing and neutralization of sludge at treatment facilities formed after surface wastewater treatment is an urgent environmental issue. The purpose of this work is to minimize the amount of waste by appropriate distribution, further application or effective disposal. One of the directions of utilization of surface wastewater sludge after biological treatment can be the production of construction materials.

2. Relevance
Treatment and disposal of sewage sludge is a very acute problem for large cities. Analysis of the composition of surface wastewater from the territories of major cities of the Russian Federation revealed a high level of contamination. The concentration of pollutants and a large volume of meltwater and rainwater in surface runoff during the year is up to 75 % of suspended substances, 20% of organic matter, 63 % of heavy metals and 65 % of petroleum products [4-6].
According to the review of technical literature, the use of sewage sludge is possible in production of [7-11].

- clay gravel (adding of mechanically dewatered sewage sludge in the amount of 3-5% to the weight of clay instead of the traditional additive – sawdust);
- wall ceramics, as a corrective additive;
- concrete (aggregate for concrete in the form of granules from a mixture of sediment with dry ash of the CHP, ground lime and gypsum);
- asphalt concrete (as a strengthening layer on the ground);
- heavy, light porous or foam concrete (as an additive 0.2-0.5% by weight);
- complex additive for cement.

One of the most frequently implemented areas of utilization is the introduction of sediment into raw mix for the production of ceramic materials. The properties of clay raw materials used in building ceramics are corrected by additives that perform different roles depending on the quality of raw materials and production technologies. Most often this adjustment relates to the improvement of the forming ability and drying and baking properties.

The use of sediment is of interest because its structure and dispersion determines a positive effect on the rheological properties of clay rocks, and the chemical and material composition of sediment during the firing of ceramic products determines the sintering process and the possible bonding that firmly hold environmentally dangerous heavy metals from sediment.

Along with the solution of the environmental issue, the disposal of sediment gives possibility to directly regulate the properties of ceramic masses and obtain products with improved specified physical and mechanical properties. The high adsorption capacity of sediment allows controlling the forming and drying properties of raw mixture. However, the use of dehydrated sediment in the form of a powder reduces the plasticity and significantly increases the molding humidity of the clay mass from 24.6 to 29.7%.

The paper [12] confirms the possibility of using sediment formed as a result of cleaning a mixture of urban and industrial wastewater and also containing heavy metals and their oxides in the production of bricks and tiles. In certain quantities the addition of precipitation does not impair the quality of ceramic products.

According to the technology developed in Yugoslavia, sediment containing heavy metal ions is used in the manufacture of bricks [13]. For this purpose the sediment is dewatered to 60 ... 80% humidity and added to the raw mixture at the stage of its homogenization in an amount of up to 5%. It is indicated that the additive does not have a toxic effect and does not affect the strength of the brick.

The paper [14] considers the possibility of using sediment in the production of complex additives to regulate the properties of cement-sand, concrete mixes and concretes. The technical result of the invention is to improve the rheological characteristics at all stages of hardening of cement-sand and concrete mixtures, as well as to improve the physical and mechanical properties of cement-sand samples. In [15], in order to extend the scope of industrial waste and to protect environment by reducing waste exported to landfills, it is proposed to develop a method for preparing the swelling component based on mechanically dehydrated sewage sludge from tanneries, which had undergone special preparation aimed to reducing its humidity and acquiring the properties of flowability.

In order to produce expanded clay there are known raw mixtures containing fatty protein residue from wastewater treatment of meat processing plants [16] as expanding additives, a mixture of digested sludge from preliminary sedimentation tanks and activated silt from biological treatment plant of municipal wastewater sludge wastewater treatment plant (excess silt), sludge after biological treatment of domestic wastewater.

The use of these additives reduces the bulk density of expanded clay. However, in industrial conditions, due to the high humidity (77-82%) of additives, it is difficult to dose and mix them with clay when preparing the raw mixture, as well as to transport and send the wet mixture to drying and firing in a rotating oven. The mixture goes unevenly, in lumps, disrupts the rhythm of the process due to jamming and stopping of individual units in the process chain.
3. Problem statement
Currently, the lack of theoretical justification and technological bases for wastewater sludge utilization with an analysis of the sanitary and chemical safety of production technology and finished products with the addition of wastewater, constrains their use and industrial implementation.

It is proposed to use sewage sludge as a complex additive that allows to improve the rheological characteristics at all stages of hardening of cement-sand and concrete mixtures, as well as to improve the physical and mechanical properties of cement-sand samples. Along with the solution of the environmental issue it is possible to directly regulate the properties of the concrete mix and obtain products with the specified properties.

To solve these issues the paper studies the properties of raw materials, physical and chemical processes and structural changes that occur when wastewater precipitation is introduced into cement and gypsum-based binders; the possibility of introducing modified plasticizing additives of wastewater precipitation into concrete is investigated.

4. Methods and materials
Sewage sludge is an aqueous suspension of mineral and organic substances of various composition and origin extracted from wastewater during their mechanical, biological or physical-chemical treatment (reagent) with a volume concentration of polydisperse solid phase from 0.5 to 10%.

Sewage sludge belongs to the class of polydisperse suspensions that are difficult to be dehydrated. As in all suspensions, the moisture in the sewage sludge is in chemical, physico-chemical and physico-mechanical connection with solid particles, as well as in free form. The volume of sediment is usually 0.5-1% (in rare cases up to 40%) of the volume of treated wastewater depending on the treatment scheme and the humidity of the sediment. Sediment humidity ranges from 85% (construction industry enterprises) to 99.5% (active sludge of biological treatment facilities) [17-19].

Wastewater pollution can pass into sediment without changing its chemical composition and structure (sediment from lattices, from sand traps, from preliminary sedimentation tanks) or with changes in composition and structure (excess active sludge or excess biofilm, sediment after reagent treatment of water, etc.) [20-22].

The paper considers the sediment of preliminary sedimentation tanks. The sediment (silt) of urban wastewater that falls out in preliminary sedimentation tanks has a humidity of 92 – 96%, is highly heterogeneous and is a gelatinous suspension of gray or light brown color with a sour smell. The size of individual particles ranges from 10 mm or more to particles of colloidal and molecular dispersion [23].

The temperature of the sediment is 12-200°C and the active reaction of the medium (pH) is the same as that of waste water, ranging from 6 to 8.

Chemical and granulometric composition of precipitation. Most of the dry matter of the sediment from primary sedimentation tanks (60-75%) and active silt (70-75%) are organic substances mainly of protein origin (up to 50%) with a fat and carbohydrate content of up to 20 and 8%, respectively. In raw sediment from primary sedimentation tanks, proteins are about 2 times less, and carbohydrates are 2.5-3 times more than in active sludge.

The dry matter of the sediment from primary settling tanks has the following elementary composition, % by weight: C-35.4...87.8%, H-4.5...8.7%, S-0.2...2.7%, N-1.8...8%, O-7.6...35.4%
The dry matter of activated sludge: C-44 ... 75.8%, H-5 ... 8.2%, S-0.9...2.7, N-3.3...9.8%, O-12.5...43.2%.

We used Portland cement of type CEM II, subtype A with slag (W) from 6% to 20% of strength class 32.5 fast-hardening (Portland cement with slag CEM II/A-W 32.5 B) meets the requirements of normative and technical documentation.

We used crushed stone from albitophyre fraction from 5 to 20 mm, LLC "Ust-Kamensky quarry". The content of clay lumps, % by weight: 0,00. Grade of crushed stone by strength (shatter): M-1400. Grade of crushed stone by abrasion: I -1. The content of weak rock grains, % by mass: 0,00. Grade of
crushed stone by frost resistance: F – 300. Bulk density of crushed stone, t / m³: 1.43. Stability of crushed stone structure against decay, %: 1.2. AEFF of natural radionuclides, Bq / kg: 95.3±12.5.

As small aggregates for concrete natural sand and sand from the screenings of crushing rocks into crushed stone and their mixtures are usually used. Sand of JSC "Levoberezhny sand pit" in Marusino village was used in the work [24]. The main properties of sand were determined by the requirements of normative and technical documents: the content of dust and clay particles-1.2%; bulk density-1549 t / m³; humidity-3.8%; clay in lumps-no; specific, effective activity of natural radionuclides in the sand AEFF-49.8 Bq/kg.

Steinberg F-10, S-3H, GROS-63 MA and GLENIUM SKY 591 additives were used as modifiers.

5. Results of experimental studies

To prepare a standard concrete mix, the following materials were used: Portland cement of the M400 brand-340 kg/m³; crushed stone of the 5(3) -20 mm fraction – 1080 kg/m³; sand MK = 1.83 (fine sand), – 780 kg/m³. Indicators of compressive strength (Rсж) of a standard concrete sample at the age of 3 days - 22.2 MPa; 7 days-30.3 MPa; 28 days-40.3 MPa.

A single-factor variance analysis was carried out to determine the effect of introducing sewage sludge modified with plasticizing additives into the concrete composition on compressive strength and average density. As a factor X1 the percentage of introduction of sewage sludge in % by weight was selected, and 4 levels were set. The measured characteristics (responses) are the average density (Y1) and compressive strength (Y2). The plan of the factor experiment and test results are shown in table 1.

| No | sample's | Response $Y_1$ Rszh (MPa) | Response $Y_2$ $\rho_m$ (kg/m³) |
|----|----------|---------------------------|-------------------------------|
|    | source components: sewage sludge | source components: sewage sludge |                               |
| 1  | 100:0,1  | X₁                         | 40.6                          | 2342                          |
|    | 100:0,2  | X₂                         | 41.3                          | 2368                          |
|    | 100:0,4  | X₃                         | 43                            | 2406                          |
|    | 100:0,6  | X₄                         | 40.8                          | 2455                          |
| 2  | 100:0,1  | X₁                         | 40.5                          | 2320                          |
|    | 100:0,2  | X₂                         | 39.5                          | 2354                          |
|    | 100:0,4  | X₃                         | 41                            | 2408                          |
|    | 100:0,6  | X₄                         | 42.3                          | 2438                          |
| 3  | 100:0,1  | X₁                         | 40.7                          | 2339                          |
|    | 100:0,2  | X₂                         | 40,5                          | 2358                          |
|    | 100:0,4  | X₃                         | 40,9                          | 2415                          |
|    | 100:0,6  | X₄                         | 41                            | 2444                          |

It was necessary to evaluate the linear effects of factor X on the responses of the experiment Y1 and Y2. To do this, the variance analysis equation is solved. The significance of the factors was assessed by the calculated indicator of the Fisher criterion. The obtained data is shown in figure 1.

*Figure 1. Influence of the ratio of initial components / sediment on the compressive strength (a) and average density (b) of concrete samples.*
According to the histogram (b), an increase in the mass fraction of sediment in concrete leads to an increase in the average density, but the value does not exceed 2500 kg/m³. According to the histogram (a), the compressive strength of experimental samples is more than 32.7 MPa of grade strength at the age of 28 days and meets the regulatory requirements.

Studies have shown that sewage sludge can be used as an additive in the production of heavy concrete for various functional purposes, the optimal ratio of the introduction of sludge is 0.6% by weight.

To increase the strength, mobility from P2 to P5 (which corresponds to commercial concrete), the sewage sludge is modified with a superplasticizer. The results are shown in table 2.

### Table 2. The composition of the concrete modified with waste water sludge.

| No | Components of the mix per 1 m³ | Additive | Dosage, % by weight of cement |
|----|-------------------------------|----------|-----------------------------|
| 1  | 300 Cement, kg                | Crushed stone, kg | Sand, kg | Sewage sludge, l | Water, l | Name |  |
| 2  | 300 Cement, kg                | Crushed stone, kg | Sand, kg | Sewage sludge, l | Water, l | F-10 | 1 |
| 3  | 300 Cement, kg                | Crushed stone, kg | Sand, kg | Sewage sludge, l | Water, l | S-3H | 1.6 |
| 4  | 300 Cement, kg                | Crushed stone, kg | Sand, kg | Sewage sludge, l | Water, l | GROS-63 MA | 0.6 |
| 5  | 300 Cement, kg                | Crushed stone, kg | Sand, kg | Sewage sludge, l | Water, l | SKY 591 | 0.6 |

In figure 3, the graph of changes in the strength of concrete clearly shows how the modification of sewage sludge with a plasticizer in the ratio of 0.6%, 1% and 1.6% by weight of cement affects the strength of experimental concrete samples.

The aggregate state of sewage sludge is pasty and it helps to increase the plasticity of the concrete mix, and this effect is enhanced during the modification process with an additive. During the modification the mobility of the concrete mix increased from P2 to P5 (the draft of the cone was 24 cm).

### 6. Conclusions

A variant of systematization of materials with the use of sewage sludge is proposed, which is based on the dependence of the aggregate state of the sludge on the type of construction material. It was found that it is advisable to use sewage sludge in heavy concrete as a corrective additive, without reducing the strength characteristics. The optimal ratio of sediment introduction is 0.6% by weight. According to the results of experimental studies, the optimal composition of concrete was selected: Portland cement of the M400 brand – 300 kg/m³; crushed stone of the 5 -20 mm fraction – 1165 kg/m³; sand
MK = 1.83 (fine sand) – 736 kg/m³; sewage sludge-16.8 kg/m³; water-168 l / m³. A concrete composition based on a modifying additive (sewage sludge + chemical additive Steinberg GROS-63 MA) has been developed, which has a compressive strength of 23.1 MPa at the age of 3 days, and a compressive strength of 41.4 MPa at the age of 28 days. The addition of a modifying additive (sewage sludge + chemical additive Steinberg GROS-63 MA) affects the mobility of the concrete mix, which increases from P2 to P5. Further research is expected to address questions of structure formation and study of the interface of sludge in the composition of concrete; study on chemical composition of precipitation and physical-mechanical properties of construction material.

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