The use of incineration waste to improve the properties of the bases

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Abstract. Innovative ways of using furnace dust to improve the strength of soil-cement are analyzed. It is proposed to solve the environmental problem of utilization of this material, when using the addition of furnace dust during the construction of soil-cement elements. The samples were kept immersed in water for 28 days in order to gain strength, until laboratory tests. The removal ash before the experiment was sieved on a 4 mm sieve. Strength of soil-cement samples with the addition of furnace dust and pellet ash (with the main content of sunflower husk with a percentage of 5% by weight of cement) was studied. It is established that the average compressive strength of the samples with the addition of Mykolai CHP furnace dust with a fraction of inclusions up to 4 mm in the amount of 5% increases the compressive strength by 30%. It was found that the content of organic matter (ash from burning sunflower husks) in soil-cement reduces its strength.

1. Introduction

Construction of foundations accounts for a significant part of the total construction costs. One of the effective ways to reduce the cost of foundation construction is to improve the characteristics of the soils that form the basis for the foundation. This can be achieved by impregnating the soil with cement slurry – cementation. As a result of the process of cement hydration, a material of quite significant strength is obtained – soil-cement [1].

The use of soil-cement as a material for making foundations and strengthening foundations is an effective way to reduce the cost of construction because it uses soils that lie directly at the base of construction sites. Soil cement has recently been widely used to improve the properties of foundations, for the construction of various industrial and civil structures. The use of soil-cement structures for the main technological structures of biogas plants is promising [2].

Soil-cement structures are gaining more and more popularity in foundation construction, namely: arrangement of retaining walls of ditches; arrangement of anti-filtration curtains; strengthening of landslide slopes; strengthening the foundation of existing foundations with inclined, horizontal and vertical soil-cement elements; railway embankments; improving the construction properties of peat, loess soils, bulk, weak soils (E <5 MPa) [1,3].

From the point of view of manufacturability of production process, soil-cement piles (elements) have advantages over all other stuffed piles that their manufacturing requires no additional actions for the maintenance of walls of wells (casings, drilling muds, special shells, etc.). We know boring and mixing and jet method of their production. The latter has the advantage of its productivity and greater capabilities in depth and diameter of soil-cement piles. With the drilling method less cement and
simple equipment are used, as result the estimated the cost of soil-cement is less. However, there is a problem of low strength of cement as a material. Soil-cement piles lose their bearing capacity mainly on the material and not on the soil.

To increase the strength of soil-cement, various researchers have proposed additives in the form of lime, clay, various plasticizers [5], sand and tailings (mineral waste) [4].

On the other hand, there is a problem of accumulation of waste from enterprises, namely ash, ashes and slag waste from thermal power plants (CHP), which occupy large areas.

It is known that approximately 50% of all electricity produced in Ukraine belongs to thermal power plants. According to statistics, the ash content of extracted coal is growing every year, and accordingly, thermal coal supplied to thermal power plants averages 26.3 to 36.2%, which leads to an increase in the amount of ash slag, as well as ash, which is removed with the exhaust gases. There is a constant accumulation of ash and ashes and slag waste in the ash dumps of thermal power plants, which today amount to approximately 400 million tons. As a result, the design capacity of most CHP ash dumps is being filled, and obtaining new areas is problematic. In order to solve this problem, a certain amount of ash slag after studying the content of radioactive and toxic components, is used as a raw material in the building materials industry, as well as in road construction as a backfill when laying the base of asphalt pavements [5].

Solid waste from thermal power plants – ashes and slags – are close to metallurgical slag in composition. In terms of chemical composition, 80 to 90% of these wastes consist of SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO with significant fluctuations in their content. In addition, the composition of these wastes includes residues of unburned fuel particles (0.5 to 20%), compounds of titanium, vanadium, germanium, gallium, sulphur, uranium [6].

M.S. Malyovanyn (2017) proposes to use CHP waste for the purpose of making additives by mixing a dispersed mineral additive – CHP furnace dust with plasticizer. As a plasticizer using sulphate soap, and the components of the modifier are mixed in the following ratio: furnace dust of thermal power plants 97 to 99 %; sulphate soap – 1 to 3 % [7].

N.V. Blaschuk and I.V. Maevska (2017) propose to add furnace dust in order to improve the properties of soil-cement elements [8]. These authors investigated the properties of soil-cement with a content of fly ash (from 20 to 80% of the cement content, respectively from 3.4 to 15% of the soil weight). It was found that the use of ash as a mineral additive in such quantities in the production of soil-cement gives a positive effect. By adding the optimal amount of ash, the strength of soil-cement structures can be increased.

2. Purpose of the Work
The purpose of the article is to study the influence of the Mykolaiv CHP furnace dust and of ash from burning sunflower husks on the strength of soil-cement.

3. Methodology and Research
Soil-cement as a material is not just a mechanical mixture, but a system consisting of two, very complex in its content and properties, multicomponent systems – cement and soil. The main leading factor in the radical transformation of soil properties is cement – a polydisperse and polymineral system, a product of fine grinding of clinker, capable of forming a stone-like body after the addition of water [4, 10].

Soils, in turn, are considered as solid polydisperse very complex systems, many properties of which are determined by the laws of dispersion of substances. Under natural conditions, the soil in most cases is a three-phase system consisting of solid, liquid and gaseous phases. The ability of soils to show complex interactions with the substances added to it is greatly enhanced by the fact that soils are also polydisperse systems.

With the strengthening of soils with cement, the absorption of cations and anions is possible. Chemical absorption plays a significant role and is accompanied by chemisorption processes, as a result of which hydrolysis and hardening of cement in soil-cement follow slightly different patterns than in concrete or mortars. Depending on the value of metabolic capacity and composition of exchange cations, different soils, even with the same particle size distribution, have quite different
physical and mechanical properties that significantly affect the stability of soils in engineering structures.

In the technological process of soil-cement preparation the decisive factors are: a) the maximum degree of grinding of soil microaggregates; b) the accuracy of dosing of cement (or other binders) and the uniformity of its mixing with the soil; c) the optimal degree of moisture (water-cement ratio) and uniform distribution of moisture in the mixture; d) the maximum compaction of soil cement at the corresponding optimum humidity; e) the optimal mode of humidity and temperature during hardening of soil-cement [4].

According to the instruction, clay soils are suitable for production of soil-cement. Of these, loess and loess loams and sands meet the requirements the most.

According to experimental data, the values of physical and mechanical characteristics significantly depend on the conditions under which the soil-cement is made. In the production of soil- cement in the conditions of the construction base (stationary) from the soil of the disturbed composition with the use of mixing machines, the following compaction and even heat treatment obtain the highest characteristics. When soil-cement is produced directly in the soil massif, according to one of the above technologies, the quality of mixing the mixture decreases, its additional compaction and heat treatment are practically impossible. The presence of water in natural soils, especially below its level, significantly increases the water-cement ratio (W/C) of mixture, which reduces the density of soil-cement and respectively its mechanical characteristics.

The disadvantages of soil-cement piles include their low strength of the material. As a result, the bearing capacity of such piles by material is much less than by soil.

Recently, a significant amount of waste in Ukraine has been incineration waste (ash; furnace dust). Due to the significant rise in energy prices, the use of solid fuel boilers has recently become popular. Sunflower husk pellets are used as fuel for heating large areas of enterprises, public institutions, etc.

Pellets are used to heat residential buildings by burning in stoves, fireplaces and boilers, to provide heat and electricity to industrial facilities and small settlements (using large pellets, with a high content of bark). Pellets, for the production of which bark, sawdust, wood chips, agricultural waste (sunflower husk, straw, substandard flax), as well as organic packaging materials and cardboard packaging are used, are equivalent to coal in efficiency. Sunflower husk and straw have sufficient fuel properties, close to the properties of wood fuel. Due to this, biofuels made from sunflower can be burned in boiler equipment designed for wood biomass.

The moisture content of sawn and chipped wood intended for burning in stoves and fireplaces should be as low as possible. Made from secondary raw materials that are harmless to humans and the environment, pellets emit 10–50 times less carbon dioxide (CO₂) into the environment and 15–20 times less ash than in the case of coal combustion. Pellets are used to heat residential buildings by burning in stoves, fireplaces and boilers, to provide heat and electricity to industrial facilities and small settlements (using large pellets, with a high content of bark). In addition, pellets are cheaper than coal, liquid fuel or firewood, such biofuels are convenient to transport in packaged bags and in bulk.

Such fuel is environmentally friendly and economical, but there is a problem of waste disposal (ash).

Also, annually in Ukraine thermal power plants generate about 6.5 million tons of ash and slag waste, a significant part of this waste being furnace dust. Furnace dust is formed as a result of solid fuel combustion; after it is captured by electrostatic precipitators, in the dry state the ash is selected by means of an ash collector for production needs. Otherwise, it goes with slag and water to the ash dump. Thermal power plants are equipped with filtering devices that capture ash, preventing it from entering the air. Thus, large batches of this product are accumulated, and cement companies purchase and consume about 60,000 tons of ash emissions annually.

Furnace dust is a fine material consisting of particles up to 0.14 mm in size, formed by the combustion of solid fuels at the CHP.

The ash provides a sliding effect, so the mixture is better compacted during vibration. In the case of self-compacting concrete vibration is not even required: compaction is due to gravity. This is mainly due to the smooth surface and spherical shape of the ash particles.
Most fragments of ash have a spherical shape, smooth glassy surface texture. The size of spherical particles ranges from a few microns to 50–60 microns. The particle size of the furnace dust ranges from 3–5 to 100–150 µm. The number of large particles usually does not exceed 10 – 15%. Heavier ash particles are deposited on the firebox and fused into lump slags, which are aggregated and alloy ash particles ranging in size from 0.15 to 30 mm. [6].

The Mykolaiv CHP furnace dust before carrying out experiment was sifted on a sieve of 4 mm. The content of spherical inclusions from 1 to 4 mm was up to 40%. The average humidity of the removal ash was 0.6% (Figure 1).

The experiment is carried out as follows: cement and water mixed to obtain “cement milk”. The amount of cement was taken as 20% by weight of dry soil for all series of tests. The W/C was taken as 1. Then to the cement mortar was added furnace dust, then obtained mixture was blended with soil (loam with a moisture content of 14%). The study is carried out for the amount of furnace dust of 5, 10 and 15% of the amount of cement. The prepared soil-cement mixture was mixed to a homogeneous mass for at least 5 minutes. After mixing, the soil-cement mixture is inserted into cylindrical molds with a diameter of 2.8 cm and a height of 3.5 – 4 cm.

A similar method of preparing the mixture was with the addition of pellets ash (waste from burning straw) (Figure 2, 4). The effect of additives of 5, 10 and 15% of the amount of cement (20% by weight of dry soil) was also studied.

Prior to testing, the samples were stored immersed in water for 28 days to gain strength. The tests were carried out in accordance with DSTU B B.2.7-214:2009 as for concrete, taking into account DSTU B B.2.1-4-96. The tests were performed for 6 samples in each series.

The test results of the compression samples at the age of 28 days are shown in Tables 1 and 2. The cracks that preceded the final destruction of the samples were mainly vertical in nature. In this case, we observe brittle fracture due to the accumulation of mobile dislocations in front of the obstacle (subgrain boundaries), which leads to a concentration of stresses sufficient to form a crack. When the stresses reach a certain value, the crack size becomes critical and further growth is spontaneous. Fragile fracture is characterized by a sharp, often branched crack. The size of the zone of plastic deformation at the top of the crack is small. The rate of propagation of a brittle crack is significant and sudden.

As a result of the research it was found that the average compressive strength of the samples without any additive is 2.78 MPa; with the addition of furnace dust in the amount of 5% – 3.64 MPa. N.V. Blaschuk and I.V. Maevska (2017) also noted an improvement in the compressive strength of soil-cement with the addition of a small amount of Ladyzhinska CHP (3.4 – 15% of soil weight) [8].
As we can see from Table 1, the test results of soil-cement samples for compression at the amount of furnace dust additive 5, 10 and 15% are almost the same. Therefore, it is necessary to increase the range of additives and to study soil-cement samples.

![Figure 3](image1.png) General view of the sample of the soil-cement sample with the addition of 5% furnace dust after application of the load

![Figure 4](image2.png) General view of the sample of soil-cement element with the addition of 5% ash from burning straw.

**Table 1.** Characteristics of compressive strength of soil-cement samples with the addition of furnace dust (at the age of 28 days)

| Soil-cement samples | Without additive | With the addition of furnace dust |
|---------------------|------------------|----------------------------------|
|                     | Average compressive strength, MPa | 5% | 10% | 15% |
| Average compressive strength, MPa | 2.78 | 3.64 | 3.17 | 3.13 |
| Coefficient of variation υ | 0.30 | 0.11 | 0.11 | 0.09 |

The average compressive strength of soil cement samples with the addition of ash from the burning of pellets from sunflower husks decreased.

**Table 2.** Characteristics of compressive strength of soil-cement samples with the addition of straw ash (at the age of 28 days)

| Soil-cement samples | Without additive | With the addition of ash from the combustion of straw ash |
|---------------------|------------------|----------------------------------------------------------|
|                     | Average compressive strength, MPa | 5% | 10% | 15% |
| Average compressive strength, MPa | 2.78 | 1.71 | 1.80 | 1.61 |
| Coefficient of variation υ | 0.30 | 0.24 | 0.17 | 0.33 |

**4. Conclusions**

According to the results of the analysis, it can be concluded that the average compressive strength of soil cement samples with the addition of ash from burning pellets from straw decreased. This may be due to the inexpediency of using the method of traditional technology of preparation of materials for the manufacture of experimental samples. The ash was not previously mixed with dry cement to a homogeneous mixture. It indicates the inexpediency of using such waste for soil-cement production.

The average compressive strength of the samples with the addition of Mykolaiv CHP furnace dust with a fraction of inclusions up to 4 mm in the amount of 5% increases by 30%.

Therefore, the use of Nikolaev CHP furnace dust as a mineral additive in the soil-cement elements production in the amount of 5% by weight of cement significantly increases the compressive strength. This expands the range of applications of soil-cement elements and increases their efficiency.
However, in the production of soil-cement, the rheological properties of furnace dust are important, especially the high fineness of grinding, favourable fractionation and the shape of its particles [10].

Reference
[1] Novytsky O, 2013 Methods of cement soil consolidation Bulletin of the Donbass Academy of Civil Engineering and Architecture Poltava 3 (101) pp 32 – 37
[2] Karpushyn, S.O., Klymenko, V.V. & Shynder, A.V., 2018 Patent of Ukraine No.124712. Anaerobic bioreactor for biogas and organic substrate production. Kyiv: State Patent Office of Ukraine Order 867 2016 Rules for traction calculations for train work (Moscow: JSC Russian Railways) p 510
[3] Nesterenko T, 2012 Development of a mounted deep vibrator for compaction of soil-cement piles Collection of scientific works (branch mechanical engineering, construction) Poltava PNTU 1 (31) pp 257 – 262
[4] Dao Huu Do, Tuan A. Pham, 2018 Investigation of Performance of Soil-Cement Pile in Support of Foundation Systems for High-Rise Buildings 4 (2) pp 266 – 277
[5] Burban N, Atamanyuk V Environmental aspects of the use of fly ash from thermal power plants Environmental Protection. Energy saving. Balanced Nature Management: Proceedings of the First International Congress June 28-29 Lviv pp 16 – 17
[6] Ivakhnenko A, Khlopytsky O, 2018 Formation, classification and prospects of utilization of ash-slag waste in Ukraine Theory and practice of modern science November 23-24, Odessa pp 111-112
[7] Painted M, Cooper M, Kanda M, 2018 A method of manufacturing a modifier for landslide structures No.126483 IPC C04B 28/14 (2006.01) Ukraine No. u201713144
[8] Maevska I, Goncharuk M, 2020 The effect of the use of fly ash for the arrangement of soil-cement piles. Youth in science: research, problems, prospects 2019: abstracts of scientific-practical internet conference, Vinnytsia pp 212 - 218
[9] Novitsky O, 2012 Influence of plasticizing additives on soil cement strength Collection of scientific works (branch mechanical engineering, construction) Poltava 4 (34) pp 171 – 177
[10] Zotsenko M, Vinnikov Yu, Zotsenko V, 2016 Drilling soil-cement piles, which are made by the drilling method (Poltava: Printing House Madrid) p 94
[11] Kryvosheiev P, Farenuyk G, Tytarenko V, Boyko I, Kornienko M, Zotsenko M, Vynnykov Yu, Sedin V, Shokarev V, Krysan V 2017 Innovative projects in difficult soil conditions using artificial foundation and base, arranged without soil excavation Proc. of the 19th Intern. Conf. on Soil Mechanics and Geotechnical Engineering Sep. 17 – 22 COEX, Seoul, Korea pp 3007–3010
[12] Rajesh P. Shukla 2020 Pile settlement due to soil movement induced by the abrupt breakdown of retaining wall September Acta Polytechnica 60(4) pp 338–348 DOI: 10.14311/AP.2020.60.0338