

Influence of Fly Ash Additives on Strength Characteristics of Soil–Cement as a Material for Waste Storage Construction



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Abstract Innovative ways of using fly ash 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 fly ash during the construction of soil–cement elements. The strength of soil–cement samples with the addition of fly ash (with the main content of fly ash with a percentage of 5, 10 and 15% by weight of cement) at the age of 28 and 90 days was studied. It is established that the average compressive strength of the samples with the addition of Mikolaev CHP fly ash with a fraction of inclusions up to 4 mm in the amount of 5% increases the compressive strength by 30% (at the age 28 days). The expediency of the application of fly ash for soil–cement elements in the construction of waste storage is analyzed.

Keywords Soil–cement · Fly ash · Waste storage · Compressive strength

1 Introduction

Mixing of soils with cement allows to receive quite strong and environmentally friendly material soil–cement which can be used both for preparation of the basis under the foundations, and for construction of the foundations, and also at the decision of various geotechnical problems.

In recent years, the use of resource-efficient through the development of new methods of arranging soil–cement structures is increasingly used in the construction of foundations: as bored piles, in the arrangement of retaining walls of pits and soil–cement anchors. Building envelopes are designed for the action of horizontal loading from soil pressure and groundwater, as well as on a vertical loading to the surface of the soil near the envelope. Special requirements for the strength of soil–cement

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elements and the tightness of their styling are determined for building envelopes [1]. The use of soil–cement structures for the construction of waste storage is promising.

In this case, soil–cement anti-filtration curtains are used, which can be vertical and horizontal. The thickness of anti-filtration curtains is in the range of 0.5 ... 2 m and depends on the filtration capacity, strength of soil–cement, pressure gradient [1]. Special requirements are set for anti-filtration curtains to ensure a low filtration coefficient and resistance to groundwater aggressiveness. Soil–cement is used in the installation of drilling mud, artificial reservoirs, pools, reservoirs, fountains [2].

From the point of view of manufacturability soil–cement piles (elements) have advantages over all other driven piles that at their manufacturing there is no need for additional actions for the maintenance of walls of wells (casings, drilling muds, special shells, etc.).

The most common in our country is the drilling method due to the simplicity of mechanisms for its implementation. The essence of this method is to mechanically develop and mix the soil with a binding material, which is fed in the form of a solution. Mixing of soil with binding material, as a rule, occurs in a working well (without excavation of soil), but also application of technology with partial excavation of soil or in special bunkers mixers is possible. The advantage of this method is the economy of the binding material, a constant cross-section of the soil–cement element in accordance with the diameter of the applied working auger. One of the disadvantages of soil–cement elements is their relatively low strength of the material.

On the other hand, the problem of accumulation of waste from enterprises, namely ash, ash and slag waste from thermal power plants (CHP), which occupy large areas, is relevant in Ukraine. For example, Trypillya CHP has accumulated 28 million ash slags, 140 ha. The result of waste storage is large-scale dust storms that cover nearby settlements. All this is complicated by the fact that there is no sanitary protection zone between the ash dump.

In Western Europe and Japan, ash dumps have been virtually eliminated at thermal power plants. In 1990, the European Coal Combustion Products Association was established by European electricity producers to ensure the profitable and high-quality use of ash. At modern thermal power plants, coal is burned in a dusty state. Slag is formed by the adhesion of softened ash particles. The maximum grain size of slag in the ash-slag mixture is not more than 20 mm.

Ash is removed from the furnace with flue gases (fly ash). Most ash fragments have a vitreous surface texture. The size of spherical particles varies from a few microns to 50–60 μm [3].

Ash from thermal power plants have different chemical composition depending on the type of coal burned. Ash from oil shale coal is less acidic than ash from the combustion of brown or hard coal [3]. During the combustion of coal in thermal power plants and slag, 7–9 million tons (50–200 g of ash per 1 kW-gram of produced electricity).

Kovalsky V.P., Sidlak O.S. (2014) note that the use of ash and slag waste from thermal power plants in the production of concrete and reinforced concrete products allows you to: reduce cement consumption by 10–20%; to improve physical and mechanical properties of concrete; reduce the cost of creating and operating dumps;

to release the lands occupied by dumps; to exclude pollution of air and water basins. The use of Portland cement hydration processes with the addition of 40% of CHP fly ash has proved the feasibility of replacing a significant part of the clinker component in concrete [3, 4].

Malyovaniy M.S. (2017) proposes to use CHP waste for the purpose of making additives by mixing a dispersed mineral additive—CHP fly ash [5].

Blaschuk N.V. and Maevska I.V. (2017) propose to add fly ash in order to improve the properties of soil–cement elements [6]. As a result of experiments, they found that the addition of fly ash in the amount of 3.4 to 15% by weight of the soil in the manufacture of soil–cement samples in the laboratory gives a positive effect.

2 Purpose of the Work. Methodology and Research

The purpose of the article is to study the influence of the Mykolayiv CHP fly ash on the strength characteristics of soil–cement.

Soil cement is a building material formed by mixing soil with cement mortar. It has a fairly high shear strength, but is brittle and has a low tensile strength. This leads to the formation of cracks.

Under natural conditions, the soil in most cases is a three-phase system consisting of solid, liquid and gaseous phases. Depending on the value of the exchange capacity and the composition of the exchange cations, different soils, even with the same particle size distribution, have quite different physical and mechanical properties. This circumstance significantly affects the stability of soils in engineering structures [7].

Clay soils are suitable for the production of soil–cement. Of these, loess and loess loams and sands meet the requirements the most.

When soil–cement is produced directly in the soil of the construction site, the quality of mixing of the mixture is reduced by boring-mixing technology in comparison with the production of such elements in the enterprise. In the field, additional compaction of the mixture is almost impossible. In flooded soils, especially below its groundwater level, the water-cement ratio of the mixture increases significantly. The consequence of this will be a decrease in the density of soil–cement and its mechanical characteristics. The disadvantages of soil–cement piles include their low strength of the material.

Recently, a significant amount of waste in Ukraine is incineration waste (ash).

Annually in Ukraine thermal power plants generate about 6.5 million tons of ash and slag waste, a significant part of this waste is fly ash, that is a fine material consisting of particles up to 0.14 mm in size.

The mineralogical composition of ash depends on the type of fuel used at the CHP and the conditions of its combustion. It contains metakaolin, quartz of various modifications, γ -alumina, mullite, various iron compounds, sulfur compounds and other substances, but in very small quantities. The mineralogical composition of the ash determines their activity, chemical composition and some other properties.

The true density of the individual ash fractions in most fuels can range from 2 to 5 g/cm³. The high density of the individual components of the ash is due to the fact that it is dominated by particles consisting mainly of iron compounds or minerals, with a significant density. Different actual density of ash particles obtained by burning the same fuel is associated with different chemical composition of individual fractions [8].

Storozhuk N.A. (2017) found that during the combustion of the organic part of the fuel, clay impurities that are part of the mineral part of the fuel are dehydrated and amorphized. Temperature intervals of dehydration of clay matter depend on its mineralogical composition. First, the main part of the water is released without destroying the crystal lattice of the mineral. After that, the obtained material differs in physical properties from the original mineral, has a distorted crystal structure and increased reactivity [8].

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 μ. The particle size of the furnace dust ranges from 3–5 to 100–150 mkm [6]. The number of large particles usually does not exceed 10–15%.

The Mikolaev CHP fly ash before carrying out experiment was sifted on a sieve of 4 mm (Fig. 1). The content of spherical inclusions from 1 to 4 mm was up to 40%. The average humidity of the removal ash was 0,6%.

The starting materials for the preparation of soil–cement in both laboratory and field conditions are clay-sandy soil, water, Portland cement.

For the production of the studied soil–cement samples it was used loess, yellow–brown, hard loam. The soil had the following characteristics: soil moisture 14%, plasticity limit, W_p —0.25; yield strength W_L —0.37; the density $\rho = 1.72$ g/cm³.

For the preparation of soil–cement samples it was used hydrocarbonate-calcium water, slightly mineralized, slightly alkaline, pH = 8, which does not contain harmful impurities and microorganisms, which interferes with the normal hardening of cement.

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 fly ash, then obtained mixture was blended with soil. The study is carried out for the

Fig. 1 General view of the components of the mixture: 1—loam loess disturbed structure of natural humidity; 2—fly ash of the Mikolaev CHP



amount of fly ash 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 min. 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.

Prior to testing, the samples were stored immersed in water for 28 and 90 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 and 90 days are shown in Table 1.

The cracks that preceded the final destruction of the samples were mainly vertical in nature (Fig. 2). The samples studied are subject to brittle fracture. Sample cracks when applying a vertical load usually occurred in local areas of high stress concentration. The decisive role in the destruction process was played by microstresses that occurred in the soil–cement element during the application of step load. The primary cause of microstresses is microhomogeneity and microanisotropy of the structure. Plastic deformation developed mainly in the sliding planes, while most of the body volume continued to work elastically beyond the yield strength. Uneven plastic deformation led to the development of uneven fields of microdeformations and microstresses of turbulent nature. The presence of such strong energy concentrators contributes to the formation of microcracks, the number and size of which increase as plastic deformation continues. This process of accumulation of damage—the process of plastic loosening—is the first stage of destruction. Further growth of

Table 1 Characteristics of compressive strength of soil–cement samples with the addition of furnace dust (at the age of 28 and 90 days) with coefficient of variation ν

Average compressive strength, MPa	Without additive	With the addition of fly ash		
		5%	10%	15%
R_{28}/ν	2,78/0,30	3,64/0,11	3,17/0,11	3,13/0,09
R_{90}/ν	3,06/0,28	3,91/0,13	3,40/0,08	3,33/0,08

Fig. 2 General view of the soil–cement sample, which is soaked in water for 28 days with the addition of 5% fly ash after application of the load



the crack during compression of the element is explained by the fact that it creates a concentration of stresses at its edge. The development of cracks leads to the destruction of the sample. Fragile fracture is characterized by a sharp, often branched crack. 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 at the age of 28 days and 3,06 MPa at the age of 90 days; with the addition of furnace dust in the amount of 5%—3,64 and 3,91 MPa, respectively. Blaschuk N.V. and Maevska I.V. (2017) also noted an improvement in the compressive strength of soil–cement with the addition of a small amount of Ladyzhinskaya CHP fly ash (3,4—15% of soil weight) [6].

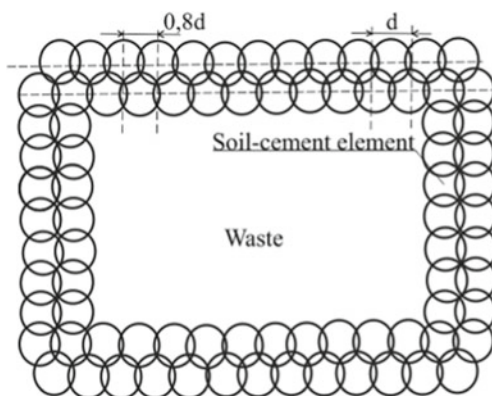
As we can see from Table 1, the test results of soil–cement samples for compression at the amount of furnace dust additive 5, 10 and 15% are almost the same. Therefore, it is necessary to increase the range of additives and to study soil–cement samples.

According to the results of research it is established that with increasing of the hardening period of samples in water up to 90 days increases the average compressive strength of soil–cement samples without additives and with the addition of the appropriate percentage of removal ash by 6–9%. For example, the average compressive strength of samples at the age of 90 days is 7.5% higher than samples at the age of 28 days.

Research is of great importance in the construction of structures made of soil–cement elements, waste storage, protective screens. One of the main indicators that must have the material used in the construction of waste storage—water resistance, sufficient strength and durability. Soil–cement is a waterproof material, its porosity is mostly closed, and the filtration coefficient compared to natural soil is reduced by 10,000–100,000 times [9]. According to the results of research, an increase in the average compressive strength of soil–cement elements over time in an aqueous medium, which increases durability. That is, soil–cement with additive of fly ash is recommended for the construction of protective screens and waste storage in flood conditions.

The following construction of waste storage is offered. On perimeters of the planned storage the monolithic vertical watertight diaphragms like “wall in the ground” from soil–cement elements is constructed (Fig. 3). It is offered to arrange soil–cement elements with addition of 5% by weight of ash of removal of the Mikolaev thermal power plant. This improves the compressive strength and durability of the structure and it will allow to dispose of waste from fuel combustion CHP. It is recommended to build soil–cement elements according to boring–mixing technology. The distance between the elements in the axes should be equal to $0.8d$ (d is the diameter of the soil–cement elements) [10–15]. This method allows you to loosen the soil without removing it. At the same time, a cement slurry is injected into the loose soil with the addition of fly ash in the amount of 5 wt.%. After that, mixing and compaction of the soil–cement mixture is performed. An important factor in the design of the storage is the choice of the location of the storage, provided that there is a waterproof layer at the optimal depth from the surface (8–20 m). Water-permeable layers can be located above it.

Fig. 3 Waste storage scheme



3 Conclusions

As a result of the researches it is established that the average compressive strength of the samples that were kept in water increases with time. In particular, the compressive strength of samples at the age of 90 days is 7.5% higher than samples at the age of 28 days.

The average compressive strength of the soil–cement samples with the addition of Nikolaev CHP fly ash with a fraction of inclusions up to 4 mm in the amount of 5% increases by 30%.

The use of Mikolaev CHP fly ash as a mineral additive in the soil–cement elements production in the amount of 5% by weight of cement increases the compressive strength. This expands the range of applications of soil–cement elements and increases their efficiency. Soil–cement with additive of removal ash is recommended for the construction of protective screens and waste storage in flood conditions, because the average compressive strength increases over time.

However, in the production of soil–cement, the rheological properties of fly ash are important, especially the high fineness of grinding, favorable fractionation and the shape of its particles.

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