Use of Heat Power Plants’ Ash in Road Construction

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Abstract. The issues of strengthening loamy soils are discussed in this paper. Studies of the high-calcium and acid ashes properties of Novosibirsk TPPs were carried out. The work reflects the possibilities of using local soils reinforced with high-calcium and acidic ashes for the construction of foundations and local highways. The increase in the bearing capacity of loamy soils can be achieved using stabilizers containing fly ash, which positively affect the bases’ properties are shown in the article. The addition of high calcium ash contributes to the formation of a more stable crystalline structure due to self-hardening. Clay component is formed within acid ash enters into chemical interaction with carbonate inclusions of the soil. Thus, stabilizer additives increase structural strength, soils acquire water resistance. The studies showed that the use of surface water-repellents together with fly ash - organosoluble silanes or water-based acrylic impregnation allowed the use of stabilized loamy soils for the construction of road pavement bases and would ensure their water resistance without cement using.

1. Introduction

Today, roads play a key role in implementing priority national projects in Russia. The road network is an essential component of the country's transport complex. The development of the entire national economy is limited by the deterioration, low density and incompleteness of the road network. The objective of the national project “High-quality and safe roads” is to take the necessary measures that will bring the road network in good condition, supplying to boost the economy in the coming years.

Currently, there is a difficult situation with pavement, which designs do not meet the requirements for durability and bearing capacity on the existing roads of the Russian Federation. This leads to rapid destruction of road surfaces, rutting. At the same time, it is necessary to repair the coatings of non-rigid clothes more often, but the overhaul periods are reduced, which leads to increase in the cost of maintaining and subsequent repair of road surface.

The network of roads in the Novosibirsk Region is 13.5 thousand km. more than 70% are the territorial roads of intermunicipal significance. These roads are crucial for the region development. They are unpaved or made of compacted gravel in most cases.

In the conditions of the Novosibirsk region, the main material for the subgrade construction is clay soils. According to the variety, they are distributed as follows: sandy loam - 2.5%, loam - 92.5%, clay - 5.0%. Clay soils (especially dusty ones) are characterized by an increased tendency, significantly changing their properties in wet and freezing weather. With waterlogging, clay soil can almost completely lose its bearing capacity. In turn, the loss of the bearing capacity of the subgrade soil leads to deformations, often completely to pavement destruction.
The most promising technology for the construction and repair of non-rigid clothes (rural roads) is the stabilization (strengthening) of local priming. Stabilization and strengthening of soils is a physical properties modification of soils by mechanical and chemical methods in order to obtain the properties necessary in road construction [1-3].

The most common method is inorganic binders’ introduction into the soil together with various additives, which allow the creation of durable soil foundations for pavement [4, 5]. Currently, ten thousands of kilometers were built and were being operated in Russia, where fortified soils (mainly cement primers) were used for foundations and coatings of road pavements. In the United States, cement reinforcement from 8 to 15% is recommended to strengthen clay soils [ASTM D558, ASTM D559 and D560].

The consumption of material resources in the roads’ construction is extremely large including cement, non-metallic materials. The need reducing for road building materials and increasing the efficiency of their use remains a critical issue. Long-term scientific research and the practice of road construction show that one of the ways to solve this problem is to use secondary resources - industrial wastes, which can be used either directly as a road-building material or as an initial product for its production [6 - 8].

In Russia, the level of this waste disposal is about 10%; in a number of developed countries is about 50%, in France and Germany is 70%, and in Finland is about 90% of their current output [9, 10].

A ways to obtain high-quality coverage is to improve the technology of building roads using fortified soils, as well as the use of industrial waste, ashes of the thermal power plant [11, 12].

Ash is used in all elements of road structures. It can be used in the upper layers of the base as a binder component as an independent binder, as mineral material reinforced with a hydraulic binder in the lower layers or enter the body of the embankment as anthropogenic soil, depending on the composition and properties [13 - 15].

2. Mathematical processing of the research result

Currently, the following basic mineral binders for soil stabilization are known: cements, lime, water glass, fly ash, dust from electric filters of lime kilns, cement, metallurgical slags, calcium and magnesium chlorides, etc.

The use of available industrial waste or its compositions is possible in order to reduce traffic and the cost of road construction. One of the most effective, cheap and universal methods of strengthening is the use of ash and slag.

The technology of building pavements from soil reinforced with additives containing ash and slag materials is a good alternative for roads construction in areas remote from places of stone materials extraction. There are three main reasons why the technology of soil strengthening is relevant in our time: environmental, economic and technological.

The aim of this work is compositions selection based on ashes of thermal power plants that increase the stability of soils during the roads construction.

Ash and slag can be used in the processing of materials and soil stabilization as:

- granulometric additives to adjust the composition of soils or stone materials;
- independent slow hardening binder (high calcium fly ash.);
- active mineral additive mixed binder in combination with cement or lime [16].

Among the industrial wastes of the Novosibirsk Region, the first place is occupied by thermal power plant ash from solid fuel combustion in volumes, particular high-calcium ash from Kansk-Achinsk brown coal and acid ash from burning Kuznetsk coal. The main difference between these Kansk-Achinsk coals from other types of solid fuel is that the bulk of the calcium and magnesium compounds are contained in the organic component in the form of finely divided calcium humates. A feature of the high-temperature pulverized combustion of the Kansk-Achinsk coals is full melting, ash
mass averaging, binding of calcium oxide particles to silicon and aluminum oxides, which leads to the formation of stable silicate and aluminosilicate compounds.

In the 80s of the last century, numerous studies were carried out on the use of high-calcium and acidic ash, slag and ash-slag mixtures in various building materials, including for strengthening soils in Russia. Positive results were obtained, industrial approbations were carried out, regulatory documents for their application were developed [SST 25818 - 91, SST 26644 - 85, SST 25592-91].

In recent years, the geography of Kansk-Achinsk coals supplies are expanded, the conditions for their combustion have changed, so the results of previous years cannot be used in practice without additional research. In addition, high-calcium ash is characterized by instability of composition and properties, which requires constant monitoring of their performance. Negative facts of rash application already exist. The results of such experiments can discredit the very idea of using this unique product for many years. Researches of ash and slag waste are currently being carried out in the field of concrete, cement, road construction, but the consensus of experts has been formed.

3. Results
The authors conducted a study of high-calcium ash of the Kansk-Achinsk brown coal (HCA) and acid ash of stone Kuznetsk coal (KUZ), currently burned at the thermal power plant in Novosibirsk. The basic chemical and physicomechanical parameters were determined (see Table 1).

Table 1. Oxide content in ash.

| Material          | SiO₂  | Al₂O₃  | Fe₂O₃ | CaO   | CaOfr | MgO   | SO₃     | p.p. |
|-------------------|-------|--------|-------|-------|-------|-------|---------|------|
| High calcium ash  | 46.8 - 51.0 | 10.5 - 12.9 | 7.0 - 7.9 | 25.1 - 48.0 | 4 - 12.3 | 4 - 7.8 | 1.0 - 2.7 | 0.2 - 1.65 |
| Coal ash          | 52.7 - 56.3 | 15.6 - 21.8 | 4.52 - 8.9 | 1.4 - 4.6 | - | 1.2 - 2.1 | 0.2 - 0.73 | 2.63 - 7.3 |

The analysis results show that ash of the Kansk-Achinsk coal is characterized by a high content of silicon oxide, the spread and the value of total and free calcium oxide.

Quality factor is determined by the formula:

\[
Kk = \frac{\text{CaO} + \text{MgO} + \text{Al}_2\text{O}_3}{\text{SiO}_2} = 1.15 - 1.25, \text{ indicates its low self-activity.}
\]

Scanning electron microscope was used to study the microrelief of individual particles composing ash. Ash consists of various sized particles of irregular or spherical shape, which are a mixture of crystalline and amorphous phases, both primary components and those resulting from clay melting and carbonate components of brown coal. It has been established that ash (HCA) consists of more than 50% glass phase, as evidenced by microphotography (see Figure 1).
Figure 1. Micrograph of high calcium ash.

X-ray phase analysis showed that high-calcium ash has a diverse mineral composition: it contains hydraulically active minerals and oxides: CaOfr, CaSO_4, β-C_2S, MgO; inert components: SiO_2, Fe_2O_3, Fe_3O_4.

Figure 2. The results of x-ray phase analysis of high-calcium ash (HCA).

The research results show that the high-calcium ash of the Novosibirsk TPPs is characterized by significant compositional instability, the reduced physical and mechanical properties and it does not meet the requirements of the new standard [SST 25818-2017 Fly ash of thermal power plants for concrete].

Acid ash of Kuznetsk coal consists mainly of β-SiO_2, quartz; mullite 3Al_2O_3 · 2SiO_2, hematite α-Fe_2O_3, reactive silicate glass. The presence of 76 - 80% glass phase, Kk = 0.6 - 0.7. They are distinguished by the ability to bind calcium hydroxide (Table 2).

Dusty loamy soils with the following characteristics were used to assess the effect of the thermal power plant’s ash additives: average humidity was 13.1%, upper plasticity - moisture at the yield stress W_L was 31.9%, lower plasticity - moisture at the rolling border was W_p - 19, 6%, plasticity index I_p was 12.3%. Loams were carbonate, the pH of the aqueous extract was 11.

Soil was dried and aggregates were crushed, before manufacturing passing through a 1.25 mm sieve. The optimum humidity of the mixture was adopted - 11 -12%. Soil was mixed with each water addition, covered with a damp cloth and held for at least 15 minutes. Soil - mineral mixtures were made by pressing at a pressure of 15 MPa using samples with a diameter of 4 sm.

After aging, we tested the stabilized soil for strength in the dry state, after capillary water saturation.

Preliminary control compositions of the soil were tested without additives, with the addition of well-known stabilizers - cement (12%) and quicklime (10%).

It is known that the hardening conditions of binders in a mixture with soil differ from the hardening conditions in concrete with pure mineral aggregates, as calcium ions released during cement hydration.
are absorbed by soil particles. The main minerals of the soil exhibit maximum adsorption capacity in the first 4 to 8 days. Clay minerals and dusty particles from the main mineral formations (feldspars, quartz, calcite) actively adsorb calcium hydroxide in the first 5 days of hardening, after the process gradually fades. Therefore, it was decided to conduct tests of stabilized soils at the age of 14 days. The test results are given in table 3.

**Table 3.** The values of the control composition.

| No. compositions | Composition | Relative strength, (average values),% |
|------------------|-------------|--------------------------------------|
| 1                | Soil        | 100                                  |
| 2                | Soil + 10% lime | 123                                 |
| 3                | Soil + 12% cement | 151                                |
| 4                | Soil + (12 - 20)% HCA | 70 - 91                            |
| 5                | Soil + 12% (HCA + lime - 1: 1) | 99                                |
| 6                | Soil + 12% (HCA + cement - 1: 1) | 100                               |
| 7                | Soil + (12 - 20% KUZ) | 121-142                            |

The capillary absorption test in the laboratory was carried out under extreme conditions, which implies direct contact of the samples with the surface of the water, and not in wet sand. The tests established the insufficient water resistance of unstabilized soils composition No. 1 (table 4). A complete loss of structural strength is noted, the sample becomes plastic, "sprawls". Samples with VKZ, despite the decrease in strength, retained the structure and mechanical properties (No. 4).

Compounds with KUZ (No. 7) showed an increase in strength and water resistance.

Its modification was tested with various hydrophobizing and polymer additives to improve the construction and technological characteristics of the zologrunt.

We analyzed the effect of impregnations and polymer additives of various types to study the possibility of hydrophobization:

**MK** - surface impregnation with an aqueous solution of potassium methylsiliconate,

**SS** - surface hydrophobization based on a mixture of silanes and siloxanes in an organic solvent;

**AL** - surface treatment with an aqueous solution of acrylic latex;

**SAD** - water styrene-acrylic dispersion additive (4%).

**Table 4.** The experiment’s results.

| No. compositions (table 1) | Compositions | Sample condition after saturation with water | Kwr |
|----------------------------|--------------|---------------------------------------------|-----|
| 1                          | Control sample (100% primer) | complete loss of structural strength, goes into a state of viscous dough | 0   |
| 4                          | Soil + HCA  | retains structural strength and ability to absorb mechanical stress | 0.28|
| 5                          | Soil + HCA + lime | retains structural strength and ability to absorb mechanical stress | 0.35|
| 6                          | Soil + HCA + cement | retains structural strength and ability to absorb mechanical stress | 0.40|
| **1**                      | MK treated water repellent primer | loses structural strength, becomes plastic | 0   |
| 4**                        | Water repellent primer SS | retains structure and ability to perceive mechanical load | 0.31|
| 5**                        | Impregnated primer AL | retains structure and ability to perceive mechanical load | 0.33|
| 6**                        | Soil + HCA + treated with water repellent SS | retains structural strength and ability to absorb mechanical stress | 0.37|
| 7**                        | Soil + HCA + AL treated | retains structural strength and ability to absorb mechanical stress | 0.38|
| 7***                       | Soil + 20% KUZ treated with SS water repellent | retains structural strength and ability to absorb mechanical stress | 0.40|
| 7****                      | Soil + 20% KUZ treated with AL impregnation | retains structural strength and ability to absorb mechanical stress | 0.39|
4. Conclusion

The test results show that high-calcium ashes of thermal power plants do not contribute to increasing the strength characteristics of loamy carbonate soils, but significantly improve the structural strength during water saturation.

The addition of acid ash allows both mechanical strength and water resistance of loams to be increased.

Treatment with an aqueous solution of potassium methylsiliconate (PM) and the introduction of aqueous styrene-acrylic dispersion (SAD) in the additive does not increase the water resistance of the samples.

The positive effect of hydrophobization was noted with the surface application of organosoluble silanes (SS) and an aqueous solution of acrylic latex (AL).

Ash soil is one of the promising and economical materials for the roads construction. However, despite the positive experience, the use of high-calcium ash has a negligible effect on their strength properties as a loam stabilizer. At the same time, the soil retains structural strength and the ability to absorb mechanical stress with full water saturation. This indicates the formation of a more stable crystalline structure due to self-hardening HCA. Strength loss can be avoided by using surface treatment with polymer compositions (siloxane and acrylic) after water saturation.

The use of acid ash additives from thermal power plants allows significantly increasing the bearing capacity and water resistance of soils. Probably, acidic ash enters into chemical interaction with carbonate inclusions of the soil, the clay component is forming. It was possible to increase the water resistance of loams and reduce soaking. Thus, the use of acidic ashes is more appropriate for carbonate soils. Surface impregnation with solutions of water repellents gives an additional effect.

The use of complex methods - additives of thermal power plant ash and surface hydrophobization can reduce the purchase cost of non-metallic materials, replace the traditional reinforcing additive - cement. Soils strengthen with ashes can be used for the construction of pavement foundations and local roads.

It should be borne in mind that the practical use of ash requires constant monitoring of their quality. Only this way can the scientific and practical basis be used for their stable in road construction.

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