

## DEVELOPMENT OF A TECHNOLOGY FOR THE DEVICE OF STRUCTURAL ELEMENTS OF ROAD SURFACING MADE OF HUMUS SOILS USING THE «MADOR» MODIFIER

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**Statement of the problem.** When performing road repair works using the technology of cold recycling, when installing foundations from reinforced soils or inert materials, in some cases there is a problem of getting humus clay soils into the structural layer of the pavement. Also, when solving special technical problems, such as the construction of temporary roads, the construction of roads for the passage of agricultural machinery during the spring thaw, there is a need to strengthen humus clay soils to ensure the movement of vehicles along the arranged layer. This circumstance led to the need to develop a technology for the device of a coating layer or a base made of humus soil using various inorganic binders, including in combination with the additive "MADOR", necessary to improve the physical and mechanical characteristics of the structural layers of pavement made of cement-reinforced materials.

**Results.** The technology of work on the construction of a layer of pavement using humus clay soils is presented. The review of the results of physical and mechanical as well as physical and chemical studies of the effect of the modifier "MADOR" on the structure of clay humus soil reinforced with cement used for the construction of structural layers of pavement is presented. The results of studies of the structure of the grunt reinforced with cement together with the modifier "MADOR" are presented.

**Conclusions.** The possibility of using the developed technology has been established and the positive effect of using the "MADOR" modifier to strengthen the humus clay soil has been predicted.

**Keywords:** highways, soil reinforcement, cement, "MADOR" modifier, study of the microstructure of materials.

**Introduction.** In the territory of the Voronezh region, there are lots of humusized soils, i.e., „chernozems“ (blackearth) which is extremely restrained in its applications when passed through by highways. The standard engineering solutions are removal of chernozem soil from the road construction site, as well as consideration of the possibility of its stabilization or reinforcement with inorganic binders. In compliance with the regulatory requirements, all types of dusty and clay soils with a plasticity of no more than 12 are used to consolidate cements, while it is not allowed to make use of soils containing humic substances in the amount of 2 % by weight in I and II road climate zones, more than 4 % in III—V zones. While repairing highways by the method of cold recycling, humus soils with an amount of humus not exceeding the one set by requirements of the regulatory documents for consolidating them with cement can enter the structural layer from the curb, from the underlying layers of the soil of the roadbed or the slope part. Also, in the case of solving special technical problems, such as the construction of temporary access roads or those for heavy machinery during a muddy season, there

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might be an industrial need to utilize the above soils to consolidate them with cement as a road base or coating. This calls for the development of technical solutions to ensure they are appropriate in these cases.

According to the experience of domestic and foreign construction, in order to address the tasks at hand, the use of a single inorganic binder in the form of lime or cement typically fails to provide the required physical and mechanical properties of a reinforced layer of humusized soil.

A wide array of additives, modifiers and stabilizers are being commonly used in road construction while strengthening soils with inorganic binders for improving their physical and mechanical properties [3, 6, 7, 11, 12, 15, 17–20]. A large number of studies have been conducted on the effectiveness of additives in soil reinforcement with inorganic binders [2, 4, 16, 21] and some positive experience has been gained in the field of highway construction and repair [1, 5, 9, 10, 13, 14]. In compliance with the regulatory requirements, chemical additives that meet the requirements of the relevant regulatory documents are used to increase the strength, frost resistance and load-bearing capacity of the structural layer [8]. Through the course of many years of research, the rule has been established in the requirements of regulatory documentation that the use of cement additives in soil reinforcement should be justified for a specific type of road work conditions. To date, various manufacturers have been offering a variety of additives to cement for consolidating materials and as the base of the highway. For a comparative assessment of the effect of the modifier on the physical and chemical properties of the cement-reinforced material, studies of the *MADOR* modifier (SRT 16308651-001-2022) were conducted.

**1. Investigation of the effect of quicklime on the physical and mechanical properties of reinforced humus soil.** To investigate and develop methods for strengthening humus soils, samples of blackearth were taken from agricultural lands of the Rossoshansky district of the Voronezh region with a natural soil moisture content of 26 %. In order to identify the characteristics of the selected soil sample, laboratory studies were carried out for further assessment of the possibility of consolidating the soil with an inorganic binder. According to the laboratory studies, the number of plasticity of the soil is 17.96, which corresponds to clay. The humus content in the test sample is 12.43 %, which is beyond the upper regulatory limit (4 %) by more than 3 times. Also, in order to bring this soil into a waterlogged state, which is observed in conditions of spring thaw, an additional 5 % of water is introduced into the soil. The total soil moisture is 31 %.

In the first experiment, quicklime was used as a binder in the laboratory studies for consolidating humusized soil. The soil was strengthened in 2 stages:

Stage 1. Preliminary introduction of 5 % lime;

Stage 2. Consolidation with an additional 15 % lime occurred after 3.5 hours. The percentages of the binder were taken to the mass of wet soil, with a humidity of 31 %.

As a result, 2 series of samples were prepared for the laboratory studies:

Series 1: humusized soil with 5 % lime over 100 % moist soil;

Series 2: humusized soil with the preliminary introduction of 5 % lime and the introduction of an additional 15 % lime after 3.5 hours.

Fig.1 shows the appearance of a sample of humusized soil treated with 5 % lime and an untreated soil sample.

As the above approach to consolidating humus soils with abnormal characteristics with binders implies their possible use for structural elements of temporary access roads, driveways for agricultural

machinery or for soils of a working layer of roads with a low traffic intensity, laboratory tests were performed in compliance with GOST (ГОСТ) 23558-94 "Mixtures of Crushed Stone-Gravel-Sand and Soils Treated with Inorganic Binders for Road and Airfield Construction".



**Fig. 1.** On the left is a view of humusized soil treated with 5 % lime, on the right is a view of humusized soil not treated with limestone

Through the course of the studies, the following physical and mechanical parameters were identified: compressive strength  $R_{CS}$  of dry samples after 7 days of hardening under normal conditions (as an indicator identifying the possibility of opening the movement of construction vehicles); compressive strength  $R_{CS}$  of dry and water-saturated samples after 28 days of normal solidification followed by calculation of the coefficient of water resistance and water absorption after 2 days according to the weight gain of the samples after they are in the water prior to the strength tests. Fig. 2 shows a view of the molded samples of series 1 and 2 prior and following the compressive strength test.



**Fig. 2.** On the left is a view of the molded samples. On the right is a view of the samples following their compressive strength test after 28 days

The parameters of the physical and mechanical properties of the studied samples are in Table 1.

Table 1

Indicators of the physical and mechanical properties

| Name of an indicator   | Sample indicator values |          |
|--|-------------------------|----------|
|  | Series 1                | Series 2 |
| Compressive strength $R_{cs}$ of dry samples after 7 days of solidification in normal conditions, MPa    | 1.59                    | 5.47     |
| Compressive strength $R_{cs}$ of dry samples after 28 days of normal solidification MPa                  | 2.27                    | 5.94     |
| Compressive strength of $R_{cs}$ samples after 28 days of normal solidification and 2 days in water, MPa | 1.28                    | 3.30     |
| Water absorption after 2 days in water, %  | 5.42                    | 5.93     |
| Coefficient of water resistance after 28 days of solidification and 2 days in water                      | 0.56                    | 0.55     |

The test results of clay soil with 12.43 % humus of Series 1 reinforced with 5 % quicklime, showed the vintage strength of M10. Testing of clay soil with 12.43 % humus of Series 2 reinforced with 5 % quicklime followed by the addition of 15 % quicklime after 3.5 hours, showed the label strength of M20. At the same time, the coefficient of water resistance in both series is of low importance.

As a result of the research into the development of technology for consolidating humus soils with normalized values exceeding the humus content, it was confirmed that technological techniques for consolidating humus soils call for the development of non-standard methods using various modifying additives to boost their properties.

**2. Investigation of the effect of cement on the physical and mechanical properties of reinforced humus soil.** In order to develop technological techniques that make it possible to consolidate humusized soil with inorganic binders and make the resulting material suitable for special technical solutions, a method has been developed that consists in "fixing" such soil with cement holding a technological break with subsequent destruction as well as adding the amount of cement necessary to consolidate it combined with a modifying complex additive that allows for an increase in the strength physical and mechanical characteristics of cement-reinforced soil in line with the requirements of the regulatory documents. Soil "fixing" is regarded as boosting its strength and water-physical properties by introducing dosages of binder that are beyond the stabilization standards, i.e., more than 2 %, but without making sure the physical and mechanical characteristics are in line with the regulatory requirements of the reinforced soil. The field of application of the technology being developed for "fixing" humus soils with subsequent reinforcement is the construction of structural elements of temporary access roads, driveways for agricultural machinery or for soils of a working layer of roads with a low traffic intensity. The implementation of this method in capital construction for roads of high categories with a high traffic intensity calls for a large complex of experimental studies as well as development of separate regulatory documents and is a separate scientific area. In this paper, the fundamental possibility of using this method with the necessary complex of laboratory tests is considered. The research results confirm the hypothesis about the possibility of using additives to obtain the required physical and mechanical characteristics in combination with the suggested method of "fixing" soils with subsequent reinforcement to the regulatory requirements. A sample of humusized soil was also used in the laboratory studies.

The number of plasticity of the soil under study is 17.96, which corresponds to clay, the humus content in the test sample is 12.43 % (with an upper regulatory limit of 4 %). Laboratory samples were prepared at the optimal humidity in compliance with GOST (ГОСТ) 23558-94.

Two series of samples of humusized soil treated with cement were prepared in the laboratory.

Series 1 was reinforced with cement in a volume of 240 kg/m<sup>3</sup> of the mass of dry soil. Series 2: cement of 40 kg/m<sup>3</sup> was pre-injected into the soil followed a day later by cement in the amount of 240 kg/m<sup>3</sup> of the dry soil mass and the modifying complex additive *MADOR* in the amount of 2.5 % of the total cement mass.

As a result of the research, laboratory tests were performed on standardized parameters and additional physical and mechanical parameters (at various strength periods) that determine the hydrophobic properties of the material. The parameters of the physical and mechanical properties of the test sample are shown in Table 2.

During the laboratory tests, it was also found that the samples from Series 2, which were pre-injected with cement of 40 kg/m<sup>3</sup>, were then injected a day later with cement in the amount of 240 kg/m<sup>3</sup> of the dry soil mass and the modifying complex additive *MADOR* in the amount of 2.5 % of the total cement mass, when water got on them in a volume of 25-50 ml, they have a hydrophobic effect, i.e., water is on the surface of the split sample and is not absorbed for up to 1 minute.

Indicators of the physical and mechanical properties

| Name of an indicator   | Series 1:<br>cement 240 kg/m <sup>3</sup> | Series 2:<br>cement 40+240 kg/m <sup>3</sup> ,<br>modifier <i>MADOR</i> — 2,5 % |
|--|---|---|
| Compressive strength $R_{cs}$ of dry samples after 7 days of solidification in normal conditions, MPa    | 8.95                                      | 9.58  |
| Compressive strength $R_{cs}$ of dry samples after 28 days of solidification in normal conditions, MPa   | 11.17                                     | 12.49   |
| Compressive strength $R_{cs}$ of samples after 28 days of normal solidification and 2 days in water, MPa | 8.53                                      | 8.80  |
| Flexural tensile strength after 28 days of normal solidification and 2 days in water, MPa                | 1.19                                      | 1.05  |
| Coefficient of water resistance after 28 days of normal solidification                                   | 0.76                                      | 0.70  |
| Water absorption, %, after 28 days of normal solidification  | 2.34                                      | 2.30  |
| Compressive strength $R_{cs}$ of dry samples after 56 days of normal solidification, MPa                 | 12.87                                     | 12.16   |
| Compressive strength of $R_{cs}$ samples after 56 days of normal solidification and 2 days in water, MPa | 8.66                                      | 9.46  |
| Flexural tensile strength after 56 days of normal solidification and 2 days in water, MPa                | 1.06                                      | 1.26  |
| Coefficient of water resistance after 56 days of normal solidification                                   | 0.67                                      | 0.78  |
| Water absorption, %, after 56 days of normal solidification  | 2.73                                      | 1.87  |
| Durability after 10 cycles of freezing and thawing, MPa  | 5.67                                      | 6.84  |
| Frost resistance coefficient   | 0.66                                      | 0.78  |

The test results of clay soil with a plasticity of 17.96 and a humus content of 12.43 %, previously "fixed" with cement of 40 kg/m<sup>3</sup> and reinforced a day later with cement in the amount of 240 kg/m<sup>3</sup> and *MADOR* modifier in the amount of 2.5 % of the total weight of cement showed the best results in terms of water resistance coefficient — 0.78, frost resistance coefficient — 0.78 as well as the highest compressive strength after 10 cycles of freezing and thawing — 6.84 MPa.

**3. Microscopic studies of cement-reinforced humus soil („chernozem“). Method and methodology.** After identifying the physical and mechanical parameters of cement-reinforced humusized clay soil (chernozem), its microstructure was investigated. The microstructure of the samples and their elemental composition were studied using the scanning electron microscopy (SEM) method on a scanning electron microscope of the *Phenom XL* brand (manufacturer *Thermo Fisher Scientific*, the Netherlands) equipped with an energy dispersive detector. The survey was carried out in the electron-optical mode ( $v_{\text{yck}} = 15$  kV,  $P = 0.10$  Pa, magnification  $\times 550$  —  $\times 30000$ ). Image acquisition, processing, and analysis were performed using the *Phenom User Interface* software package. The elemental composition of the samples was identified using the *Element identification (EID)* application.

Chips of composite material with cement-reinforced chernozem were used as samples.

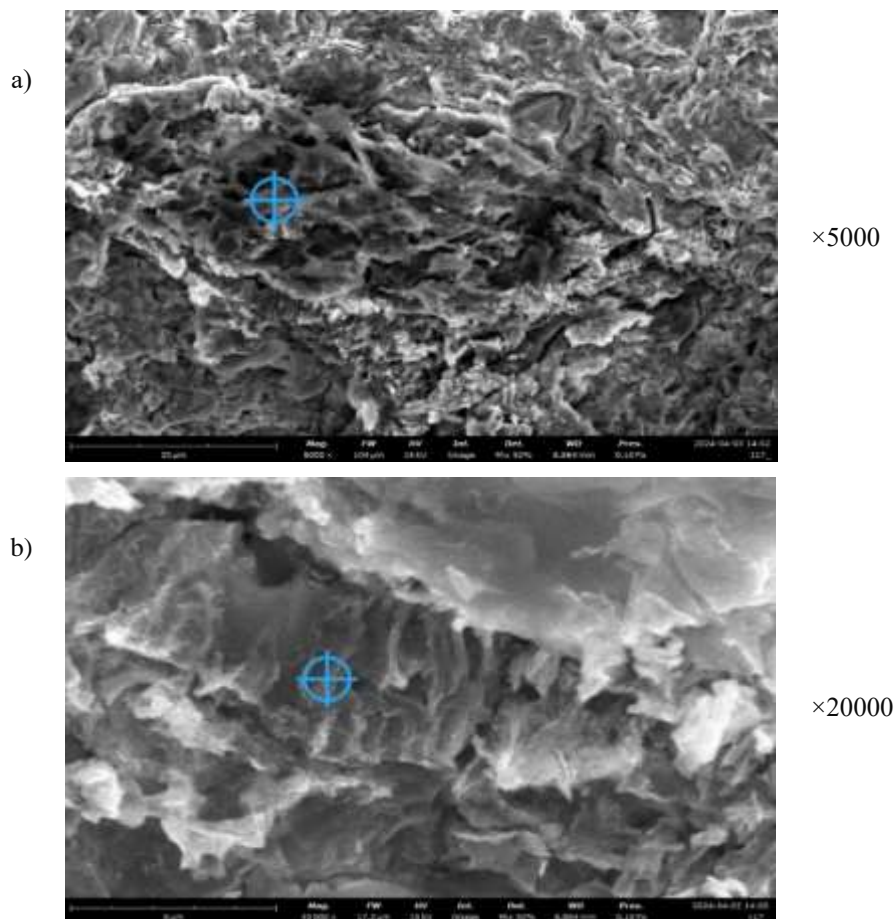
The samples were selected for each system, and the points where the survey was performed were randomly identified on each.

The name of the samples of reinforced humus soil are as follows:

Series 1: chernozem (Ch) + cement (C);

Series 2: chernozem (Ch) + cement (C) — 1 day of exposure + cement(C) + *MADOR* modifier.

Let us consider the results of the studies of the first series of the samples (Fig. 3).



**Fig. 3.** Micrographs of the sample at magnification of 5000 (a) and 20,000 (b) times of the Series 1 samples (humusized soil reinforced with cement 240 kg/m<sup>3</sup>)

At the points shown in Fig. 3, elemental analysis was also performed on a *Phenom XL* microscope using the *Phenom User Interface* software package with the mode: FW: 104 µm, mode: 15 kV — image, detector: mix — 50 %, time: 4/3/24 2:02 pm. The results of the elemental analysis are shown in Table 3 and Fig. 4.

Table 3

Element composition of the Series 1 samples

| Element Number | Element Symbol | Element Name | Atomic Conc. | Weight Conc. |
|----------------|----------------|--------------|--------------|--------------|
| 6              | C              | Carbon       | 54.448       | 41.000       |
| 8              | O              | Oxygen       | 35.886       | 36.000       |
| 13             | Al             | Aluminum     | 0.828        | 1.400        |
| 14             | Si             | Silicon      | 0.511        | 0.900        |
| 16             | S              | Sulfur       | 0.448        | 0.900        |
| 20             | Ca             | Calcium      | 7.879        | 19.800       |

The results of the microscopic studies and elemental analysis of the Series 1 sample showed that its microstructure can be characterized as heterogeneous, consisting of an amorphous, gel-like mass where irregularly shaped and irregularly sized crystallites are distributed unevenly. Based on the elements in the sample and their percentage, it can be concluded that the Series 1 sample is composed of organic compounds, low-base silicate hydrosilicates and calcium hydroaluminates with admixtures of sulfur compounds. The structure of the Series 1 material has a spongy, loose structure (Fig. 4a). While 20,000 times magnified (Fig. 4b), separate rod-shaped plates and flat angular crystals belonging to the mineral portlandite can be seen.

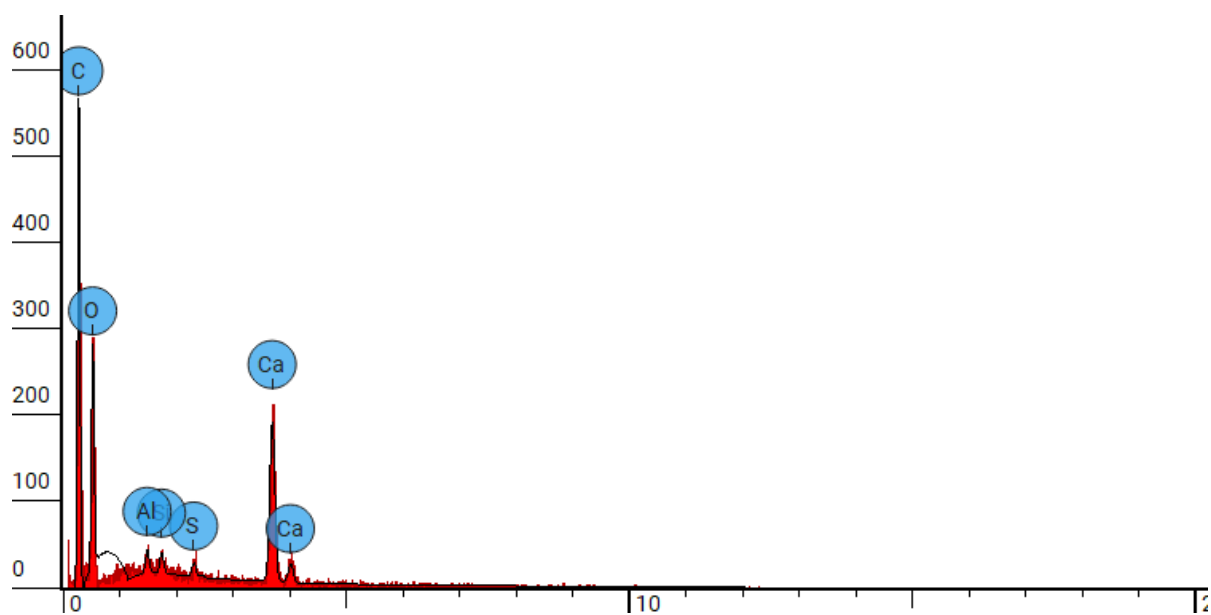


Fig. 4. Data from the elemental analysis of the Series 1 sample

The results of the microscopic studies of the Series 2 samples are shown in Fig. 5.

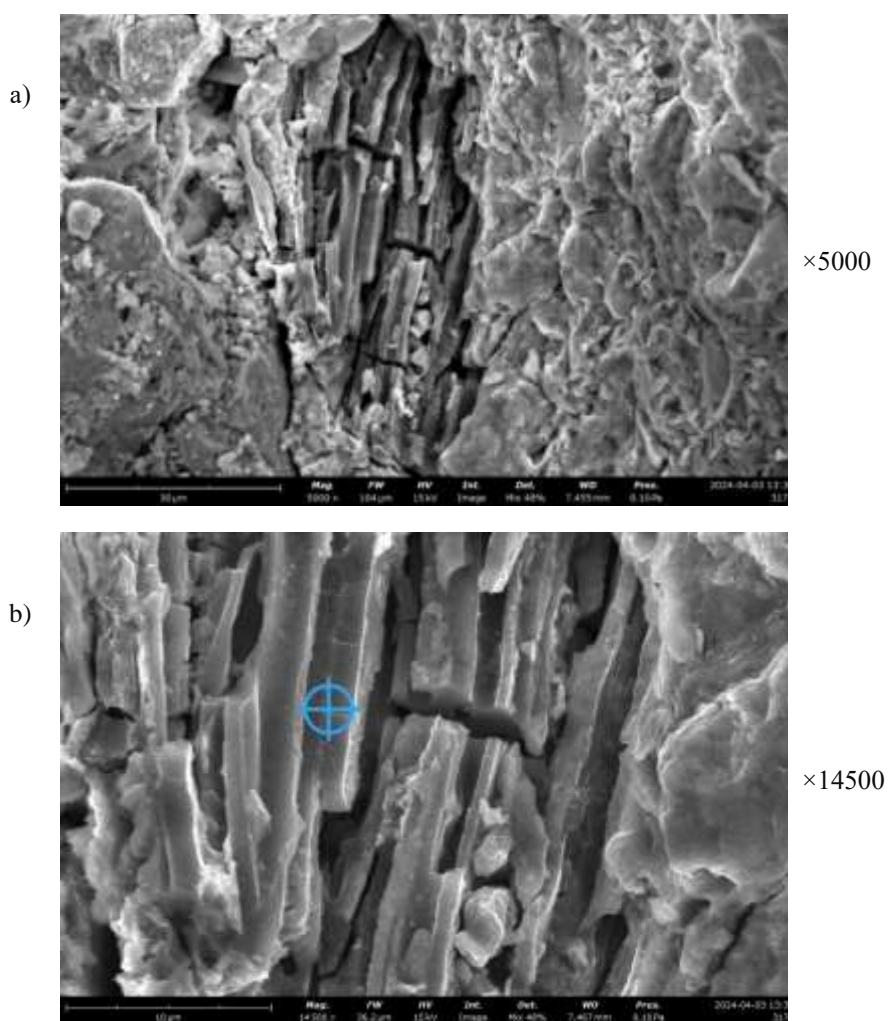


Fig. 5. Series 2 samples (humusized soil fixed with 40 kg/m<sup>3</sup> cement, then reinforced with 240 kg/m<sup>3</sup> cement and 2.5 % MADOR modifier a day later) with an increase by 5,000 (a) and 14,500 (b) times

Micrographs show that compared with the Series 1 structure, the one of Series 2 samples has a distinct crystalline grid consisting of particles of different sizes tightly fused together. Additionally, there are large druses - accretions of calcium hydroaluminosilicates with nitrogen compounds represented by monolithic columns with a height of more than 10 microns with a system of capillaries.

The results of the elemental analysis of the Series 2 sample are in Table 4 and in Fig. 6.

Table 4

Element composition of the Series 2 sample

| Element Number | Element Symbol | Element Name | Atomic Conc. | Weight Conc. |
|----------------|----------------|--------------|--------------|--------------|
| 6              | C              | Carbon       | 14.245       | 10.000       |
| 7              | N              | Nitrogen     | 12.333       | 10.100       |
| 8              | O              | Oxygen       | 59.129       | 55.300       |
| 13             | Al             | Aluminum     | 4.187        | 6.600        |
| 14             | Si             | Silicon      | 8.100        | 13.300       |
| 20             | Ca             | Calcium      | 2.006        | 4.700        |

The results of the microscopic studies show a significant predominance of the crystalline structure with monolithic neoplasms of the Series 2 samples, which confirms the higher strength properties of this series compared to the Series 1 ones. The laboratory studies conducted to consolidate humus soils with cement using the suggested technology of preliminary fixation, subsequent destruction and consolidation of the material with cement and a modifier have shown their efficiency. This area might be relevant for special technical solutions, such as the construction of temporary and access roads for capital construction projects, agricultural roads and roads with a low traffic intensity. The consumption rates of cement and modifier according to the developed technology are shown in Table 5.

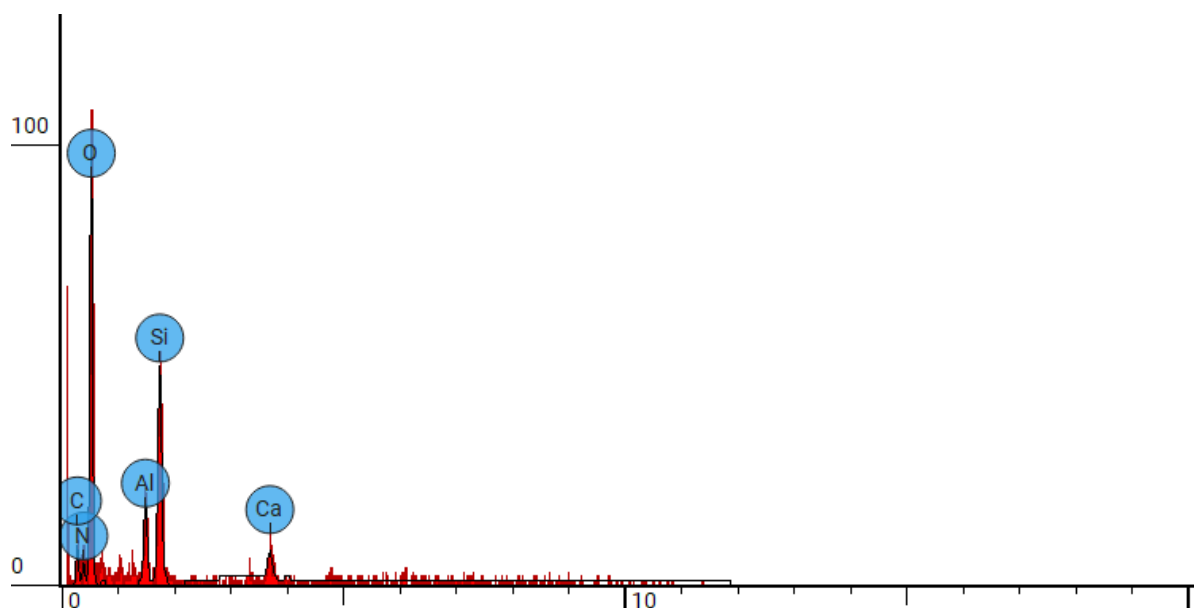


Fig. 6. Data from the elemental analysis of the Series 2 sample

Table 5

Approximate consumption of cement and a modifying complex additive

| Type of a reinforced material                  | Estimated total cement consumption, % (kg/m <sup>3</sup> ) | Estimated consumption of the modifier, % by weight of cement | Strength label according to GOST (ГОСТ) 23558 |
|--|--|--|---|
| Soils with a humus content of no more than 4 % | 12—20 (130—220)  | 2.5—3.0  | No less than M 40                             |
| Soils with humus content 4—12 %                | 25—35 (275—385)  | 2.5—3.0  | No less than M 40                             |

Soils with a humus content beyond the normalized value of 4 % must first be "fixed" with approximately 3—5 % cement.

The suggested technology for consolidating humusized soil with cement and a modifier is described as follows:

- on-site design of a drainage system;
- surface profiling of the layer to be reinforced with cement;
- sealing the surface of the reinforced layer with a technique that allows compacting the thickness of the layer below the thickness of the reinforcement in order to design a dense base under a reinforced layer;
- distribution of cement in a volume of 3—5 % to "fix" the layer of humusized soil at its optimal humidity and mixing with the soil;
- rolling up the arranged layer in 2—4 passes of the roller;
- 24—48 hours technological break;
- distribution of cement and modifier over the "fixed" layer of humusized soil at optimal humidity followed by mixing (destruction) and compaction;
- maintenance of the arranged layer.

## Conclusions

1. Through the course of studies for possible consolidation of humusized clay soils with quicklime, using it for dehumidification of waterlogged soil with improved properties has been proved possible.
2. The possibility of strengthening humusized clay soils calls for development and improvement of special engineering techniques including use of modifying additives to improve the physical and mechanical characteristics of reinforced soils, which cannot be accomplished by using a single inorganic binder.
3. A technology has been developed for consolidating humusized clay soil with the characteristics that are not in line with the requirements of the regulatory documents for consolidating it with binders in terms of humus content and plasticity which consists in pre-"fixing" the soil with cement in a volume of 3—5 % maintaining a technological break during the day, its subsequent destruction, the introduction of cement and a complex modifying additive *MADOR*.
4. The data obtained from micrographs of the samples reinforced in compliance with the developed technology show that the structure of the samples has a distinct crystalline grid consisting of particles of different sizes tightly fused together. Additionally, there are large druses — accretions of calcium hydroaluminosilicates with nitrogen compounds — which are represented by monolithic columns with a height of more than 10 microns with a system of capillaries.
5. The research results concerning the development of technology for consolidating humusized clay soil with the characteristics that are not in line with the requirements of the regulatory documents for consolidating it with binders in terms of humus content and plasticity are expected to be used for special technical problems, such as the construction of temporary access roads or roads for heavy machinery during a thaw, as a road base or surfacing, or to reduce a negative impact of such soils as they penetrate the structural layer during cold recycling operations.

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