Increase sludge-ground and ash-ground mixtures crystal lattice strength by lowering the pH environment

O Zubova, V Siletskiy, S Kukanov and T Kovalenko

Department of Industrial Transport, St. Petersburg State Forest Technical University, Institutsky per., 5U, Saint-Petersburg, 194021 Russian Federation

*Corresponding email: Ok_z19@mail.ru

Abstract. Studies have investigated the use of slaked lime in strengthening slurry of the sludge-ground and ash-ground mixtures in order to impart a higher strength to the crystal lattice, as well as to accelerate the hardening processes by reducing the acidity of the medium. The results of the exploratory study on the interaction of sandy soil with mineral binders, as well as the results of the study of the physico-mechanical characteristics of samples of ash-sand mixture with slaked lime and the study of the physico-mechanical characteristics of samples of nepheline sludge soil mixed with slaked lime are presented. The obtained results confirm that the use of localized soils reinforced by mineral binders, including industrial waste, is economically feasible, which will allow the development of forest roads infrastructure. Recycling of industrial waste in significant volumes in forest road construction will reduce the area of storage sites, thus is a priority from the point of view of ecology.

1. Introduction

Forest road construction in Russia today is in decline. Most of the forest roads were built in the USSR, and without proper maintenance at the moment, forest roads are not suitable for exploitation.

The construction of new roads is difficult and financially unjustifiable for a number of reasons: the low rental period for the scaffolding, the high cost of road-building materials, the high cost of delivering road-building materials, etc.

However, there is an urgent need to expand the forest road network. To achieve this goal it is necessary to solve the arisen difficulties. The opportunity to increase the lease period for forests today is not possible without changing forest legislation, as well as to reduce the cost of transporting road-building materials.

Reducing the cost of road building materials is the primary task facing loggers. It is possible to implement this task through the use of localized soils reinforced with mineral binders. This will lead to a reduction in the amount of materials required for the construction of a forest road, as well as reduce transportation costs, since the bulk of the material will be located directly next to the road. Also one promising solution to the problem is the use of waste industry. The low cost of waste will significantly reduce the cost of the forest road and increase its profitability.

A large number of studies have been done on strengthening weak soils, as well as on the use of industrial waste in road construction. V M Bezruk made a number of studies on soil reinforcement with various organic and mineral binders [1], G N Levchanovsky - limestone [2], P A Rebinder - physico-chemical processes of the “soil – binding” system [3, 4], L V Goncharova - fundamentals of...
soil reinforcement [5]. Studies on the use of nepheline sludge and ash from the incineration of sewage sludge from the Vodokanal SPb SUE are devoted to the works of G A Bessarab and others [6-9].

In order to solve one of the tasks and referring to the works of V M Bezruk, P A Rebinder [1, 4] and others, it was decided to make research:

on the interaction of sandy soil with mineral binders

on the use of lime in the mixture in order to increase the strength of the material.

2. Experimental Part

Purpose of the study is obtaining material with high physico-mechanical characteristics, suitable for use in the subgrade and the construction of layers of pavement, while having a low cost.

Objectives of the study:

- Search for an economically advantageous material with a high physicochemical interaction with mineral binders.
- The study of the interaction of the material with mineral binders to determine the optimal dosages of the components of the mixture.
- Comparative analysis of the results.
- Evaluation of the effectiveness of the use of new road-building materials in forest road construction.

3. Methods and Materials

The conditions of the experiment [10]:

- pressure during the formation of samples 100MPa;
- storage of samples in air-wet conditions in a desiccator for 28 days;
- water saturation in water for 48 hours;
- testing of samples with the determination of the compressive strength Rsj, water absorption Wp.

Samples were tested in the road test laboratory of the Department of Industrial Transport of the Institute of Technological Machines and Forest Transport of the St. Petersburg State Forest Technical University named after S M Kirov

3.1. The results of exploratory research on the interaction of sandy soil with mineral binders

The study of a mixture of sandy soil with mineral binders in various percentages by weight, on samples during storage in a desiccator for 90 days with soaking samples for 3 days and their subsequent testing.

The results are presented in Table 1 and in diagrams (Figure 1 and 2).

Table 1. The results of a search study of the interaction of sandy soil with mineral binders.

| №  | nepheline sludge | Sand  | Lime | Ash  | Cement | Compressive strength, MPa R | Water absorption,% W |
|----|------------------|-------|------|------|--------|---------------------------|---------------------|
| 1  | 50%              | 50%   | –    | –    | –      | 0.3                       | 9.8                 |
| 2  | 40%              | 30%   | –    | 30%  | –      | 1.7                       | 11                  |
| 3  | –                | 70%   | 8%   | 30%  | –      | 2.3                       | 6.5                 |
| 4  | 50%              | 50%   | –    | –    | 5%     | 5                         | 7.9                 |
| 5  | 50%              | 50%   | 6%   | –    | –      | 5.5                       | 4.7                 |
| 6  | 40%              | 30%   | 6%   | 30%  | –      | 10.4                      | 8.1                 |
Analysis of the study of the interaction of sandy soil with mineral binders:

- Figure 1 shows the compressive strengths, depending on the composition of the mixture. Based on the presented diagram, it can be concluded that nepheline sludge and ash from incineration of sewage sludge as independent binders are weakly active in a mixture with sandy soils. Compressive strength is in the range of 0.3 to 1.7 MPa. However, the addition of quicklime or cement in small dosages to the mixture increases the activity of hardening, which leads to a significant increase in the strength characteristics of the material. The compressive strength of samples of slime-sandy mixes fortified with slaked lime and cement reaches from 2.3 to 10.4 MPa.

- High water absorption due to the structure of the material. Nepheline sludge when hardening forms a cellular structure with high porosity and, consequently, greater water absorption (up to 11%).
The most dense structure and low water absorption (4.7%) is created by the interaction of nepheline sludge with lime.

3.2. Studies of the physico-mechanical characteristics of samples of ash-sand mixture with slaked lime. Based on the analysis of the exploratory study, experiments were conducted on the interaction of ash from the incineration of ash from the Vodokanal St. Petersburg State Unitary Enterprise with astringents in order to find the optimal lime dosages leading to the formation of a favorable acidity environment to form the strongest material structure and crystallization lattice.

The results are presented in plots (Figure 3 and 4).

Figure 3. Dependence of ultimate compressive strength of water-saturated samples of the ash-sand mixture from lime dosages.

The regression equation with the dosage of lime 2-10% is:

\[ R = 0.35x + 0.93; R^2 = 0.9661 \]  

Figure 4. Dependence of water absorption of samples of ash mixture from the dosage of lime.
The regression equation with the dosage of lime 2-10% is:

\[ W = 0.0743x^2 - 0.2117x + 4.886; R^2 = 0.9951 \] (2)

Analysis of the study of the physicomechanical characteristics of samples of ash-sand mixture with slaked lime:

- Figure 3 shows a plot of the compressive strength of samples of the ash-sand mixture versus lime dosages. Strength increases with increasing dosages of lime from 1.4 to 2.7 MPa. Slaked lime lowers the acidity in the mixture, this leads to the formation of a solid crystallization lattice in the ash-sand mixture. Low strength at 2-6% dosage of lime due to the fact that the lime is not enough to reduce the acidity in the mixture. Increasing the dosage of lime leads to an increase in the strength of the material.

- Figure 4 shows a graph of water absorption of samples of the ash-sand mixture from lime dosages. Water absorption increases with increasing dosages of lime from 4.73 to 5.7%. This range is within the regulatory requirements for road construction materials.

3.3. Studies of the physicomechanical characteristics of sludge-ground samples mixed with slaked lime

The results are presented in plots (Figure 5 and 6).

![Figure 5. Dependence of the compressive strength of water-saturated samples of a mixture of ground, nepheline sludge and binders from lime dosages.](image)

The regression equation with the dosage of lime 2-10% is:

\[ R = 1.1171x + 0.1067; R^2 = 0.9843 \] (3)
Figure 6. The water absorption of samples of a mixture of sludge, ground and binders from the dosage of lime.

The regression equation with the dosage of lime 2-10% is:

\[ W = -0.1729x^4 + 2.181x^3 - 9.009x^2 + 14.194x - 2.4167; R^2 = 0.9853 \]  

(4)

Analysis of the study of the physicomechanical characteristics of sludge-ground samples mixed with slaked lime:

- Figure 5 shows a plot of the compressive strength of samples of a mixture of soil, nepheline sludge and binders on lime dosages. The interaction of lime and nepheline sludge is a significant increase in strength with increasing dosages of lime from 0 to 10%. Compressive strength increases 4.7 times, from 1.5 to 7 MPa. This indirectly confirms the chemical interaction of lime and nepheline sludge.

- Figure 6 shows a graph of water absorption versus lime dosages. Water absorption increases with increasing dosages of lime to 8% and ranges from 4.8 to 8%. As already established, lime is a catalyst for nepheline sludge. Thus, with an increase in the dosage of lime, it can be said that the crystal lattice was formed more fully. Since the crystal lattice of a mixture of lime with nepheline sludge has a cellular structure, with a large number of pores, this leads to an increase in water absorption due to the presence of open pores. When the dosage of lime 10%, apparently, the number of open pores decreases, which leads to a decrease in water absorption by 5.5%.

4. Conclusions

As a result of research on the use of lime to strengthen the sludge-ground and ash-ground mixtures, it has been established that the introduction of 6–10% lime into the material gives a higher strength to the crystal lattice, and also accelerates hardening processes by reducing the acidity of the medium. At the same time, the strength of ash-ground mixtures, fortified with lime, reaches 2.7 MPa with a water absorption of 6.5%, which corresponds to the strength mark M20-M30 of road construction material according to GOST 23558–94 [11], and the strength of sludge-ground strengthened with lime, reaches 5.5 MPa with water absorption of 4.7%, which corresponds to the strength grade M50-M60. The ratio of nepheline sludge to the soil is 5: 5, and the ash from the incineration of ash with the ground is 3: 7. Thus, the use of nepheline sludge can significantly increase the strength of the material, while achieving low water absorption, which indirectly indicates a high frost resistance of the material. Due to its high frost resistance, it is possible to use the material when building insulating layers. If necessary, disposal of waste in forest roads can be applied ash from the burning of precipitation and
nepheline sludge. It is recommended to use ash-bearing ground in terms of strength in the subgrade and lower layers of road pavements of forest roads, and the sludge extractor is suitable for making any layers of subgrade and pavement.

The use of localized grounds reinforced by mineral binders, including industrial waste, is economically feasible, as it will reduce the cost of building a forest road, and due to its technological accessibility will allow the development of forest road infrastructure. Recycling of industrial waste in significant volumes in forest road construction will reduce the area of storage sites, thus is a priority from the point of view of ecology.

References

[1] Bezruk V M 1971 Strengthening of soil in road and airfield construction (Moscow: Transport) p 246
[2] Levchanovsky G N, Markov L A and Popandopulo G A 1977 Lime soil reinforcement in road and airfield construction (Moscow: Transport) p 149
[3] Rebinder P A 1979 Surface phenomena in dispersed systems. Physico-chemical mechanics. Selected Works (Moscow: Science) p 384
[4] Rebinder P A 1978 Surface phenomena in dispersed systems. Colloid chemistry. Selected Works (Moscow: Science) p 368
[5] Goncharova L V 1982 Basics of soil reinforcement (Moscow: Transport) p 140
[6] Bessarab G A, Suvorova N A, Kotochigov M V and Gavrilov A V 2012 The use of new materials for the construction of forest roads with large volumes of timber transportation Materials of international research Conference “Actual Problems of the Forestry Complex Development” – Vologda.:VSTU I pp 72-77
[7] Bessarab G A, Salminen E O, Zubova O V, Suvorova N A and Artemyev V V 2013 Materials of the international scientific conference. New building materials. Works BGTU-Belarus, Minsk. BSTU. I p 23-27
[8] Bessarab G A, Suvorova N A, Prosekova S A, Krasnov R V and Eliseev A A 2014 Improving the properties of road-building materials from a mixture of granite sifting and nepheline sludge, with a change in its crushing/ Materials of the international scientific conference “Actual problems of the development of the forest complex” – Vologda.: VSTU. I p 20-23
[9] Zubova O V and Bessarab G A 2008 Studies of the shear stability of road bitumen-sandstone mixtures/ SPb.: News of the St. Petersburg Forestry Academy. 184 p 143-148
[10] Zubova O V, Siletsky V V, Kozlov A P and Kuznetsov K V 2018 Studies of road mixtures based on the soil of the forest zone and nepheline sludge with additives of mineral binders News of the St. Petersburg Forestry Academy. 223 pp 187-200. DOI: 10.21266 / 2079-4304.2018.223.187-200.
[11] GOST 23558–94. Mixes of crushed stone-gravel-sand and soils treated with inorganic binders for road and airfield construction. Technical conditions