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Road Soil-Concretes on the Basis of Clay Rocks

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Abstract: The paper presents general characteristic of clay rocks in the region of Kursk Magnetic Anomaly (KMA). The work describes the technique for remolding soil-lime samples and soil-concrete samples, presents research methods for microstructure of natural and synthesized samples. The authors have formulated principles for selecting raw materials, development of effective soil-concrete and their rational use in road construction, depending on the genesis, mineral composition and size of sorption intake of clay rocks. The mechanism of structure formation and strengthening of soil-concrete on the basis of KMA clay rocks was established. The paper revealed the character of the influence of mineral composition and genetic characteristics of clay raw materials on the processes of structure formation of matrix while synthesizing cement soil-concretes. The authors have developed compositions of soil-lime mix on the basis of clay soils of KMA region for reinforcement of the road bed of the road pavement. Research proposes compositions of soil-concrete, using clay rock modified by lime-containing wastes and cement, as well as roadbed construction technology. The above compositions allow obtaining soil-concrete of 7.5 MPa with the account of technical coeffficient on clay soils with plasticity from 9 to 22.

Key words: Clay soils of KMA region · Reinforcement of soils with binders · Soil-concretes · Roadbed of motorway

INTRODUCTION

Currently, in many regions of the Russian Federation due to disproportionately rapid growth of transportation costs, lack of break-stone and transition to the construction of reinforced bases for highways, the use of local raw materials has become urgent. This significantly reduces materials consumption of road pavement and increases technological, economic and operational parameters of automobile road construction.

It seems that the region of Kursk Magnetic Anomaly (KMA), in which 70-80% of the territory is covered by clay sedimentary rocks of different genesis, composition and structure, the use of these rocks for road construction with reinforced soil is cost effective.

Soil concrete by modern standards is a multi-component artificial construction composite formed by hardening in natural conditions of rationally chosen mixture consisting of sedimentary rock (soil), commonly found along the road, binders, a set of aggregates and water. Aggregates (organic and mineral) are introduced to control the processes of new formations synthesis [1, 2] and creating the sceleton of the frame crystallization structure inside which are aggregates with the coagulation and condensation structure and the quality of soil concrete decreases in the direction from the crystallization structure.

Major contribution to solving the optimization problem of structure formation processes in concrete and soil concrete in particular, has been made by Y.M. Bazhenov, V. Bezruk, A.K. Birulya, P.A. Zamyatchensky, N.N. Ivanov, S.S. Morozov, V.V. Ohotin, M.N. Pershin, I.A. Rybev, S.M. Sergeev, V. M. Sidenko, A.J. Tula, M.M.Filatov, I.I.Cherkasov, S.V.Shestoperov and others, as well as foreign researchers [3-12].

However, soil concrete composites also have some significant disadvantages restricting their use in the pavement. Soil concrete layers have poor

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resistance to wear while directly influences by moving car wheels. Soil aggregates taking a significant volume in the sand-clay-concrete structure, deform and tear away from the thin surface layer at traffic blows. The loss of integrity, accompanied by cracking, shrinkage is observed due to temperature and shrinkage strain, heavy traffic loads. Therefore, the aim of this research was to increase the efficiency of soil concrete with the account of genetic characteristics of clay rock in KMA region to build consolidated bases for pavement.

Technique: To solve the problem of developing composition, production technology of soil concrete from KMA clay rock and their use in road construction we used modern methods of investigation to ensure the accuracy of the results.

Under laboratory conditions physical characteristics of soils (natural moisture, plasticity, density, total porosity) had previously been studied with standard techniques.

Soil concrete samples were synthesized by the following technique: original dried samples were crushed, which was followed by sample grinding in a ball mill until the sample was passed through 0.315 mm screen. Further the soils were thoroughly mixed in specific proportions with lime containing wastes and left to exposure for one day, after curing cement was added into the mixture.

Soil and lime samples were obtained in three ways:

- Original soil + 3% of lime-containing wastes;
- Original soil + 5% of lime-containing wastes;
- Original soil + 10% of lime-containing wastes.

Soil conrete samples were obtained in four ways:

- Original soil + 10% of cement;
- Original soil + 10% of cement + 3% of lime-containing wastes;
- Original soil + 10% of cement + 5% of lime-containing wastes;
- Original soil + 10% of cement+ 10% of lime-containing wastes.

Active lime was 33%. Cement - CEM I 42.5N grade. Remoulding of soil concrete samples occurred at optimum mix humidity on 10-ton press by compaction method with the load of 10-15 MPa, as this load is accepted in construction technology - this is the average road leveler pressure on the roadbed.

The sample cylinders obtained (3 cm in diameter and 3 cm high) were exposed to in natural ambient air and moist conditions at 20°C. Tests were conducted with the intervals of 1, 3, 7 and 28 days. In this case, compressive strength and frost resistance of the samples were determined.

Microstructural studies of samples were conducted with the use of HITACHI scanning electron microscope SEM 800 (Japan). The image was taken in the secondary electron emission mode. To obtain high-quality SEM images we used the technique of vacuum thermal samples spraying. Spraying was carried out with gold and foil with thickness of 10-20 nm.

Basic Part: The study of geological structure of KMA, the study of material composition and technological properties of surface exposed rocks (soils), allowed to classify them according to the composition and formation conditions (Fig. 1).

The most widespread and having the commercial value among KMA clay rock are three genetic types of soils (aeolian-eluvial-deluvial, marine forecoast lagoonian and deluvial), with the surface exposure or exposure under a thin black soil layer, occupy a significant area of Belgorod region.

The most common soils of KMA region refer to coarse clay rocks saturated with fine quartz of sedimentation and diagenesis zone (Fig. 2). We established the nature of changes in natural moisture, plasticity number and density with depth, which allows to predict the soil concrete compositions for the roadbed and subgrades of automobile roads. The specificity of the mineral composition KMA clay rocks is the presence of a thermodynamically unstable compounds, such as mixed-lattice minerals, finely dispersed poorly rounded quartz, hydrous mica with imperfect structure, less frequently Ca^{2+}- montmorillonite and kaolinite.

Due to the peculiarities of the genesis, resulting in corrosion processes, hydration, leaching and hydrolysis, regeneration, the original source rocks were destroyed, due to their minerals new compounds were formed, including a large number of free silica. Thus aluminosilicates are characterized by a variable chemical composition and with imperfect crystal, presence of mixed-layer formations and quartz surface is to corroded to different extent [13].

In most samples of eocene-quaternary there is great content of fine substance which, according to its morphology, consists of extremely fine clay particles, the content of which, depending on their genetic type, ranges from 5 to 45%. (Fig. 3).

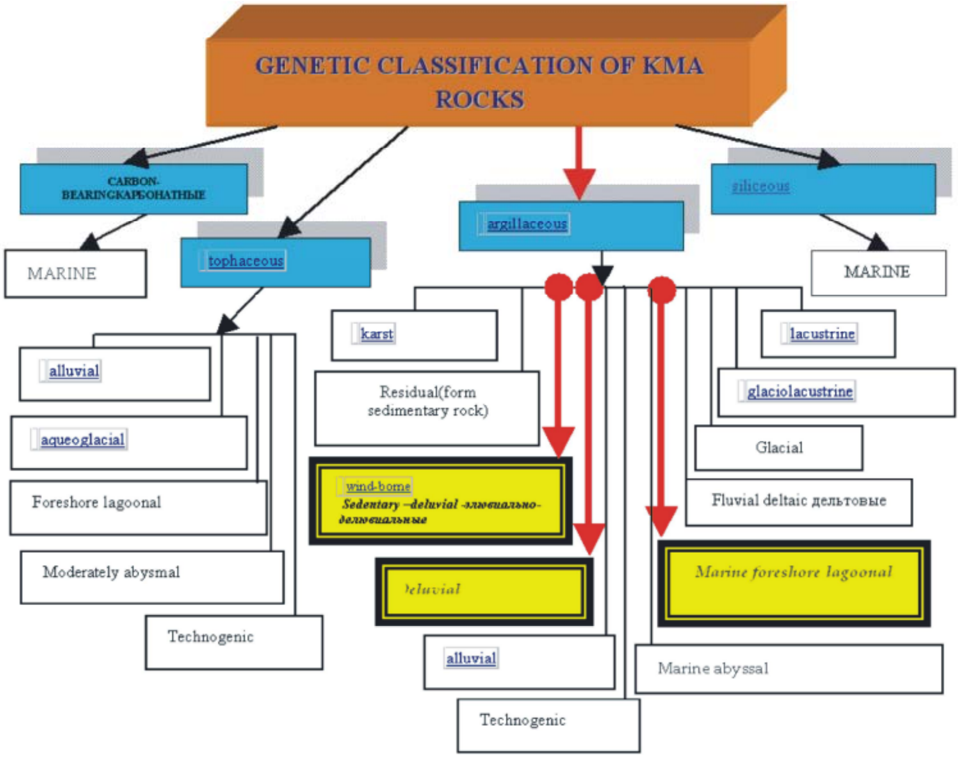


Fig. 1: Genetic classification of KMA rocks

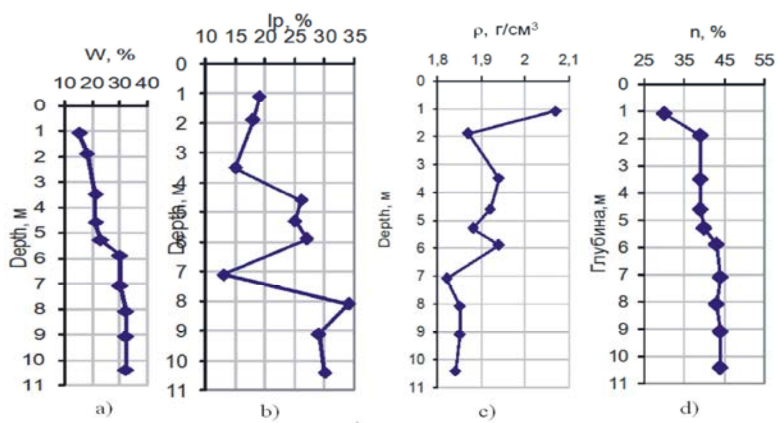


Fig. 2: Distribution graphs for physical and chemical properties of Eocene-quaternary clay with depth of: a - natural humidity; b - plasticity number; c- density; d - general porosity

One of the most important measures to improve the service period of roads is to strengthen the subgrade. For this purpose, it was proposed to use lime containing wastes of sugar factories, the amount of which in Belgorod region is several hundred thousand tons.

During storage, lime has partially been hydrated and then, as a result of carbonization, turned into a mixture of Portlandite-calcite, which is evidenced by electron microscopic studies of wastes taken from various waste dump sites (Fig. 4).

The photomicrographs show two generations of portlandite - columnar and plate aggregates; the major part is represented by aggregated clusters micro-tegular weakly crystallized portlandite, well-edged calcite crystals (pinacoids) are present.

The extent of absorption of lime is a common criterion both for the study of interaction between clay minerals with calcium hydroxide under hydrothermal conditions and for assessing the accepted technological mode of ground improvement and the impact of various technological factors on this process [14].

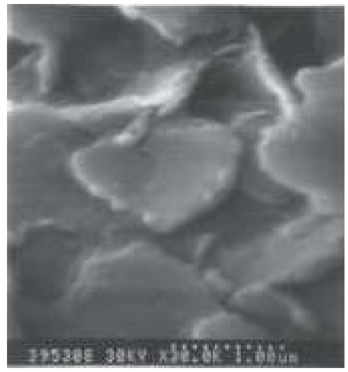
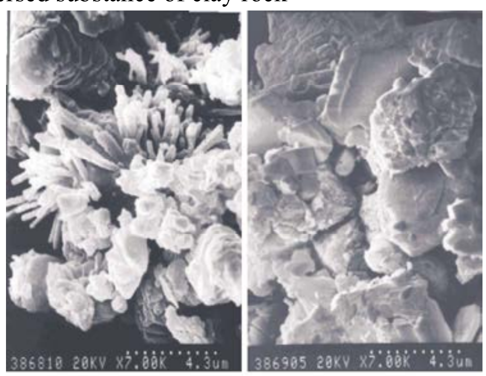


Fig. 3: **Micrographs of** finely dispersed substance of clay rock



a) b)

Fig. 4: Micrographs of lime-containing wastes from sugar factories:
a - activity above 30%; *b* - activity below 30%

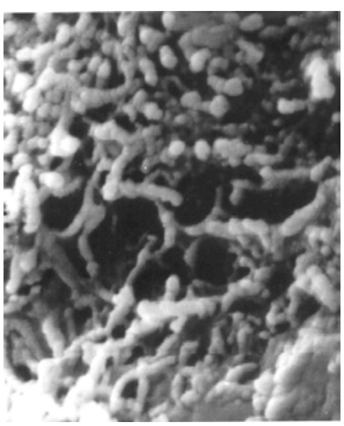


Fig. 5: Newly formed substance grid, × 30000

Interaction KMA clay rock with calcium hydroxide at low temperatures has a sorption character. Calcium ions are adsorbed on the surface of clay minerals, as well as take unsaturated bonds, located between the packages at the boundaries of aluminum and silicon-oxygen layers. The structure of the clay minerals is not changed, but only coagulation of clay particles takes place. Increasing temperature starts the process of destroying the crystal structure of clay minerals and chemical reaction of CaO with alumina and silica. As a result weakly crystalline and cryptocrystalline calcium hydrosilicates are formed. The higher the temperature, the faster the process becomes and more is the value of the maximum CaO absorption by clay.

However, apart from substitution of interlayer cations by calcium ions and calcium saturation of interlayer positions, which leads to a decrease of cationic capacity of clay minerals, we have detected X-ray amorphous new globular formations. They represent a network of newly formed materials with distinctive oolite-like constituent parts connected to each other in the form of chains (Fig. 5). This indicates that in a relatively short period of time (exposure duration of experimental samples was 28 days), not only physico-mechanical stabilization processes occur, but the chemical reaction with the formation of primordial phases.

As a result, we observe the emergence of new formations, the formation of grains of a typical crystal structure in "clay soil – lime-containing component" system. X-ray amorphous grains of new formations in the form of branched frame permeate the entire volume, linking together large soil aggregates (Fig. 6). Neoplasms

Table 1: Composition and properties of soil concrete in water saturated state

No. of composition	Plasticity number	Cement content,%	Content of lime containing wastes, %	Compressive strength, MPa 1 day.	3 days	7 days	28 days	Freeze-proof coefficient
1	9	0	0	0,2	0,2	0,3	0,5	-
2	9	0	5	0,6	0,8	1,2	1,6	-
3	9	0	10	0,8	0,9	1,1	1,6	-
4	9	0	15	0,7	0,8	0,9	1,4	-
5	9	10	0	1,2	2,4	3,4	5,7	0,72
6	9	10	5	2,4	3,6	5,1	8,3	0,81
7	9	10	10	2,5	3,7	4,9	8,1	0,88
8	9	10	15	2,1	3,2	4,6	7,4	0,82
9	22	0	0	0,2	0,3	0,3	0,4	-
10	22	0	5	0,4	0,5	0,7	1,1	-
11	22	0	10	0,3	0,5	1,3	1,8	-
12	22	0	15	0,4	0,7	1,4	1,8	-
13	22	10	0	0,7	1,9	3,1	4,5	0,63
14	22	10	5	0,9	2,8	4,8	7,3	0,67
15	22	10	10	1,4	3,7	5,4	7,9	0,79
16	22	10	15	1,3	4,2	5,6	8,2	0,76

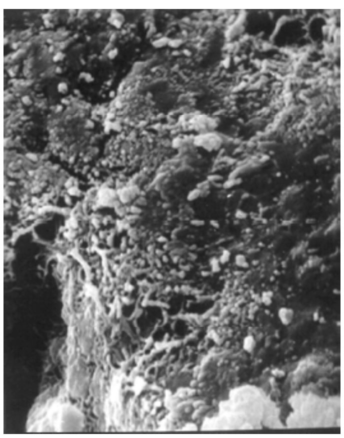


Fig. 6: Soil aggregates, joint grouting by new formations grid, × 10000

emerging in soil interstices, their formation, growth, promote joint grouting and growth in strength of artificial conglomerate [14].

Thus, the study of "clay soil - lime-containing component" system has shown that the use of lime containing wastes to stabilize clay soils allows to not only reduce the absorption capacity of soils, thus favoring the process of hydrolysis and hydration of clinker minerals, but also to form crystal structure grains - colloidal particles which may eventually become crystallization centers in the formation of cement soil concrete in the service period. It has been demonstrated that the optimal structure of cement-soil-lime composite is a structure, in which the spaces between soil particles are filled with rigid frame of new formations, cementing conglomerate as a whole [15].

This explains the difference in strength characteristics of soil concrete on the basis of KMA clay raw materials (Table 1). Activation of KMA clay rocks by lime containing wastes of sugar factories can increase compressive strength 1.3-1.8 times. Moreover, the nature and intensity of the impact is determined by the composition of clay minerals. The more Ca^{2+} +-montmorillonite and hydromicaceous minerals are contained in the clay rock, the lower is compressive strength of and-clay concrete and the more lime waste must be introduced to activate the raw materials.

It has been found that for activation of eolian-eluvial-diluvial clay-bearing soil it is necessary to introduce 5% of lime containing waste (Fig. 7). In this case, the compressive strength of soil reaches the required value with the introduction of 8-10% of cement, which is 160-200 kg per cubic meter of the mix.

If a road construction site has favourable landscape composed of Ca^{2+}-montmorillonite, hydromica or mixed-layer formations, the use of such rocks for building base course requires the introduction of up to 10-15% of lime waste. 3-5 days lime-soil mixture exposure is able not only to reduce cationic capacity of clay minerals, but also to synthesize new X-ray amorphous formations. Cement introduction into raw materials prepared this way allow to obtain composite having a tensile strength up to 7-8 MPa. The use of modification technology proposed allows to expand the range of clay rocks used, get soil cement concrete with a wide range of properties and on its basis design high quality roadbeds for automobile roads, even with the assurance coefficient of the technology, which, depending on the equipment used ranges from 1.2 to 3.

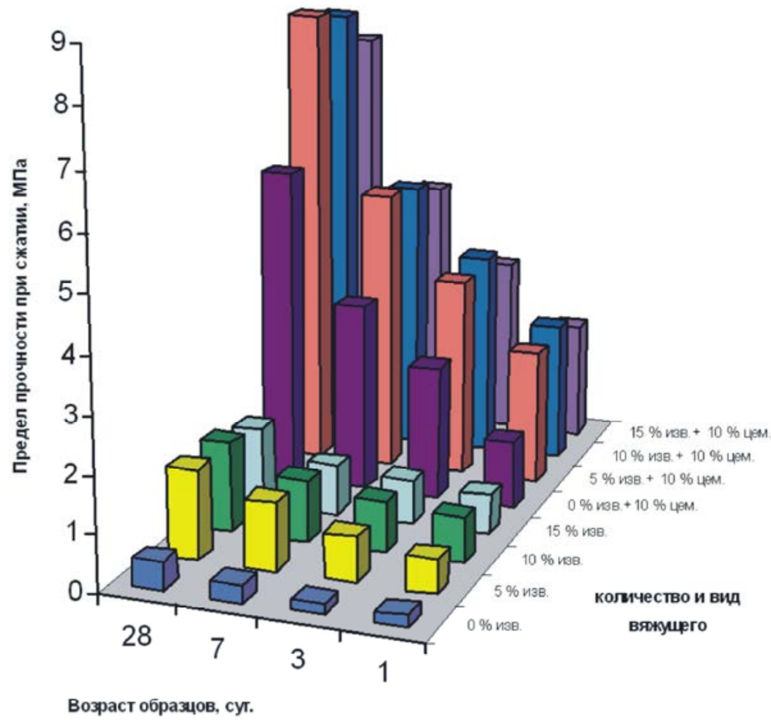


Fig. 7: Dependence of samples of soil concrete on the basis of clay-bearing soil depending on the quantity and type of binder in water-saturated condition

For the practical implementation of this technology development the technology was proposed to strengthen the subcourse and subgrade construction of roads, including: loosening the top layer of subgrade on the width of the road under construction including roadsides, distribution of lime-containing waste in the amount of 5-15% (depending on the composition of clays), introduction of appropriate quantity of water, mixing and compaction.

In the future, for the construction of consolidated bases from roadside reserves can offer transportation of pre-exposed lime-clay mixture, mixing with cement using single pass soil mixing machines, hydration, distribution across the project area, compaction.

Summary: As the experience shows the crisis recovery in many states in the world started with road construction intensification. Many regions of the Russian Federation experience shortage of break stone, which is one of the main heavy load components of road structures. Transition to use of local raw materials reinforced with inorganic binders in road bases, will not just result in getting a competitive material for construction of high quality roads, but at the same time reduce operating costs by reducing the cost of transporting the crushing stone.

A comprehensive study of the structural and textural properties of KMA soils and soil concretes produced on their basis allowed to reveal structure formation of road construction composites using clay raw materials, which are non-permanent in composition and properties, this allows the synthesis of materials with desired properties and a certain type of structural connections. Using such building materials is possible in up-to-date road structures.

CONCLUSIONS

The principles of selection of raw materials, the formation of effective sand-clay concrete and their rational use in road construction, depending on the genesis of mineral composition and the size of the sorption intake of KMA clays have been formulated, which allows to predict the most efficient production technology of soil-concrete.

The mechanism of structure formation and curing of soil concrete made on the basis of KMA clays has been revealed, which comprises chemical interaction between polymineral substance of clay rock with lime-containing waste and synthesis of gel new formation on crystals edges of clay minerals with imperfect crystal-chemical parameters resulting in transition of condensate mix structure into condensation-crystallization structure of a composite.

The character of the influence of the mineral composition and genetic characteristics of clay material on the processes of matrix structure formation during the synthesis sand- clay cement concretes has been revealed. It was found that the most promising for this purpose are the phases characterized by unfinished stage of mineralization, which include: mixed-layer formations and clay bearing soils of eolian-eluvial-diluvial genesis of the Quaternary period and opoka clay of moderate depths in KMA region.

A comprehensive study of structural and textural properties of soils and soil concrete revealed the similarity of structure formation processes of natural and man-made composites, which enables to design the structure, in the preparation of road building materials with predetermined properties. Based on the above, a model of structural transformations in the preparation of sand-clay concrete in the "clay soil - lime-waste - cement" which has allowed the following: synthesize structures with predetermined properties, spread relic structure evenly over the volume; predict emergence of particular structures in the service period.

Compositions of soil and lime mixture on the basis of KMA clay soils to be used for reinforcing pavement subgrade have been developed. The technology of the roadbed construction with the account of the identified features for modification of clay rocks has been proposed.

Soil-concrete compositions, using clays modified with lime-containing waste of sugar manufacture and cement have been proposed, as well as roadbase building technology for III and IV category roads. It has been proved that without such modifications significantly montmorillonite and opoka-like rock in KMA deposits are not suitable to strengthen the roadbases. These compositions allow to get sand-clay concrete a strength of 7.5 MPa on clay soils with the plasticity from 9 to 22 with the account of technological coefficient.

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