IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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IOP Conf. Series: Earth and Environmental Science **272** (2019) 022220 doi:10.1088/1755-1315/272/2/022220

New Construction Solutions for Geoenvironment Protection of Transport Infrastructure

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Abstract. Heavy metals are one of the most dangerous types of pollution for human, animal and plant life. The problem of pollution of geoenvironment by heavy metals during the operation of the railways is considered. To solve this problem the authors propose a new construction and technological solutions that can minimize geoenvironment pollution of transport infrastructure. These solutions are based on the use of mineral geoantidotes. Mineral geoantidotes are substances that have detoxification properties in relation to heavy metal ions. Qualitative chemical and potentiometric analyzes were used to study mineral geoantidotes. Schemes of technological operations for the creation of geoecoprotective constructions and objects are presented. New construction solutions will protect the geoenvironment from heavy metals contamination by combining geoenvironmental technology with the railway track repair or reconstruction.

1. Introduction

Railway transport has a negative influence on the environment. The main part of pollutants get into the soil, and consequently, to ground and surface water by transportation cargoes by railways and, especially, during their rash or leakage. Railway track is one of the sources of environmental pollution caused by heavy metals. Heavy metals are super-toxicants of the XXI century. They migrate into the soil, groundwater and surface water, and then they go through potable water and agricultural food grown near the railroad tracks into the human and animal organism. As opposed to other pollutants heavy metal ions are kept in soils for a long time even when a pollution source is eliminated [1].

It was determined the patterns of spreading of heavy metals in the side from the railway track in the works of some researchers [2]. According to this pattern the most polluted soil is in the interval 0-20 m and the concentration of heavy metals decreases with perpendicular movement away from the top of rail. The studies [3] showed that the samples of crushed ballast contain copper at a concentration that exceeds the maximum allowable concentration 30-190 times and 2-6 times for lead. Possible sources of ballast contamination by copper are line electric locomotives, railroad cars. Pollution occurs due to abrasion of the aerial contact wire during their operation forming metal dust. There is 1.2-1.5 million or an average of 15 tons per year of worked-out contaminated ballast formed per kilometer of track on Russian railways. It is throw out and contaminates the soil in the railroad precinct where agricultural land and human settlements may be located nearby. The priority task of «Ecological strategy» of Russian Railways is to reduce the negative impact on the environment by 70% by 2030 [4], including through the introduction of resource saving environmental technologies. Therefor the purpose of the work was development a new construction and technological solutions that can minimize geoenvironment pollution of transport infrastructure.

2. Experimental studies on the detoxification properties determination of the mineral geoantidotes

Mineral geoantidotes (MGa) is solid difficultly soluble technogenic, artificial, natural substances in dispersion form or binder systems. They have the composition corresponding to natural composition of the crust (calcium and magnesium silicates and hydrosilicates). They can pollutants decontaminate, for example heavy metals ions (HMI), by forming of difficultly soluble substances. It is spontaneous reaction ($\Delta G^0_{298} < 0$) [5-7]. It was found that some binder systems and finished materials consisting of calcium silicate and magnesium hydrosilicate have neutralizing ability against HMI [8-10]. In this connection the purpose of the experiments was to study the processes of detoxication of soils contaminated by HMI through the use of binder systems of different nature [11].

The sand has been studied as a soil that has been subjected to artificial pollution. Self-stressing and expanding cements are binder systems, which have been considered for the detoxication polluted sand. Four fractions of sand were selected for the research: 0.14-0.315 mm, 0.315-0.63 mm, 0.63-1.25 mm, 1.25-2.5 mm. For artificial sand pollution 3 solutions containing cadmium ions concentration were prepared (II) exceeding approximately permissible concentration (APC) in soil (0.5 mg / kg) in 100, 1000, 5000 times. We were prepared three solutions containing a cadmium ions concentration, which exceeds of APC in the soil (0.5 mg / kg) 100, 1000 and 5000 times. We confirmed the presence in the data solutions the cadmium ions using qualitative analysis. Experiments [11] have shown that the binder system such as expanding cement neutralizes sand containing a concentration of cadmium ions, which exceeds APC 100 and 1000 times. Because it has not happened visual changes while adding a few drops of sodium sulfide in corresponding aqueous extracts of sand and cement blends. The same results have been received in studies of aqueous extracts of sand while adding self-stressing cement. The results of the qualitative analysis of aqueous extracts of various sand fractions containing cadmium concentration of 5000 APC with different percentages of binder systems are presented in Table 1.

Table 1. The results of qualitative analysis of the presence of cadmium ions in the aqueous extract of contaminated sand depending on the binder system, its content in the sand and the sand fraction.

Binder system content in sand, %	Sand fraction, mm	Binder system	
		Expanding	Self-stressing
5	0,14…0,315	+	+
	0,315…0,63	+	-
	0,63…1,25	+	-
	1,25…2,5	+	-
10	0,14…0,315	-	-
	0,315…0,63	-	-
	0,63…1,25	-	-
	1,25…2,5	-	-
15	0,14…0,315	-	-
	0,315…0,63	-	-
	0,63…1,25	-	-
	1,25…2,5	-	-

Thus, initial studies have shown that investigated binder systems can be used for soil detoxication and reinforcement where it is needed [12]. For this purposes primarily the self-stressing cement should be used, because it neutralizes sand containing cadmium with a p article size greater than 0.315 mm and its percentage in sand from 5 to 15. Expanding cement have detoxification properties when its percentage in sand from 10 to 15.

Also laboratory experiments have shown that such construction wastes as autoclave foam concrete and silicate brick are mineral geoantidotes, because they have the composition corresponding to natural composition of the crust (calcium and magnesium hydrosilicates) can decontaminate HMI by forming of difficultly soluble substances. They can be used as geoecoprotective fillers in different railway structures in order to minimize negative impact of heavy metal ions on water resources and soil [13-15].

The notion of geoecoprotective activity has been introduced by the authors to use quantitative characteristic of geoecoprotective properties of these MGa [16]. Geoecoprotective activity, Agep, is ability of MGa (construction wastes) to neutralize pollutants independently of the mechanism of the purification process. The specific geoecoprotective activity is the ratio of neutralized pollutants mass to unit mass of MGa. Geoecoprotective activity is calculated by the formula (1):

$$A_{\mathrm{gep}} = \frac{(C_i - C_{\mathrm{r}}) \cdot V}{m} \tag{1}$$

where Agep = geoecoprotective activity of MGa, mg/g; Ci = initial concentration of heavy metal ions, mg/l; Cr = residual concentration of heavy metal ions, mg/l; V = solution volume, l; and m = MGa mass, g.

The MGa geoecoprotective activity depends on various initial concentrations in HMI solutions (Table 2). And the value of Agep of the considered materials increases, when initial concentration of HMI is increased too. The values of geoecoprotective activity were calculated for the fractions of the construction waste 0.14-0.315 mm. At the same time calculations have showed that the treatment efficiency is decreased, when the metal cation concentration is increased in the initial solution.

Table 2. The dependence of construction wastes geoecoprotective activity on initial HMI concentration in solutions (fraction of materials is 0.14-0.315 mm).

Construction waste	Geoecoprotective activity, A_{gep}, mg/g, to HMI			
	Pb (II)	Pb (II)	Cd (II)	Cd (II)
Autoclave foam concrete	2,48	22,07	1,05	5,95
Silicate brick	2,41	10,73	0,99	3,66
Initial concentration of HMI, mol /l	10^{-4}	10^{-3}	10^{-4}	10^{-3}

3. A new construction solution on creating geoecoprotective under ballast layer of railway track using binder systems

The technological solution using geoecoprotective under ballast layer and binder systems is based on geomembrane technology developed by the authors [17, 18]. Existing construction of ballast cleaning machine SCHU-800 can create such layer without removing of track skeleton [19]. Thus process technology can be carried out during the railway track reconstruction or repair.

Technological operation schematic diagram on creating geoecoprotective under ballast layer of railway track using binder systems is shown in Figure 5.

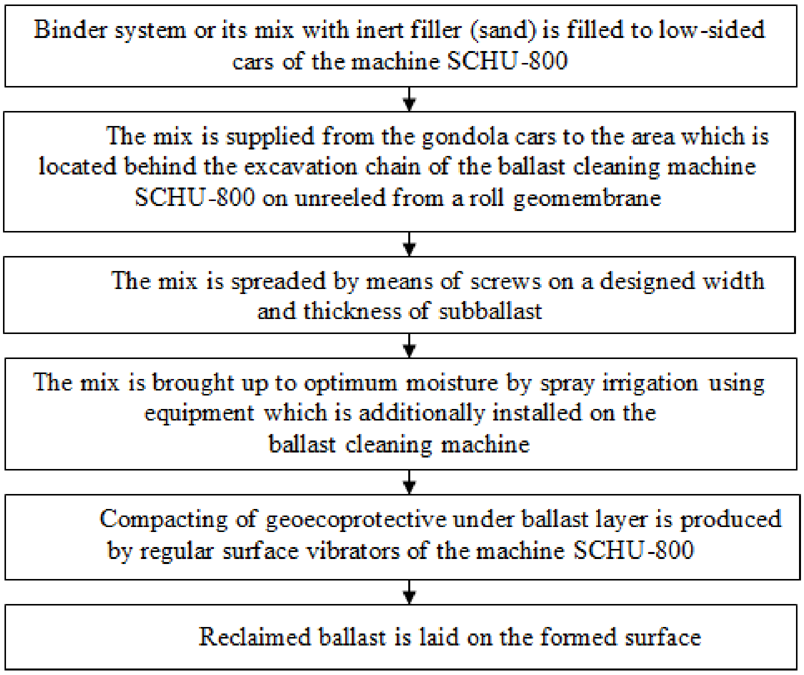

Figure 1. Technological operation schematic diagram on creating geoecoprotective under ballast layer of railway track using binder systems.

Such geoecoprotective construction (Figure 2) will provide ballast decontamination from heavy metals and others pollutants before they together with runoff get into the drainage system along the roadbed. Also a partial setting strength and consolidation of the ballast fine fraction can occur during spray irrigation process.

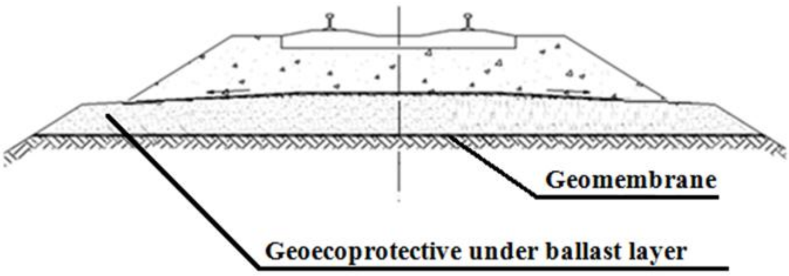

Figure 2. Railway track with geoecoprotective under ballast layer.

4. A new construction solution for soil protection from pollution in railroad precinct using construction wastes

Since a large amount of fouled ballast is thrown into a ditch, it is required to develop effective ways to protect the soil from pollution in railroad precinct. In the opinion of the authors, the use of highly efficient mechanisms and machines for railway track repair and environmental protection must be a complex technical solution [20]. Therefore, one of the ways is to use the ballast cleaning RM-80 machine [19]. The machine is used during the process of overall repair of track for ballast cleaning from pollutants of fraction less than 25 mm. Pollutants are fed into the pocket wagon or are placed in the railroad precinct. As the smallest fraction of ballast contains HMI it is necessary to provide measures for their neutralization. For this purpose the most effective solution is the use of such MGa as construction wastes.

Technological operation schematic diagram for soil protection from pollution in railroad precinct using construction wastes is shown in Figure 3.

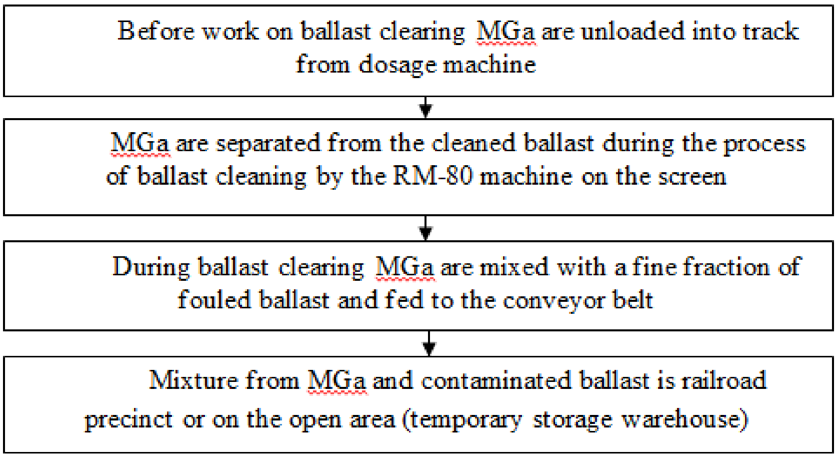

Figure 3. Technological operation schematic diagram for soil protection from pollution in railroad precinct using construction wastes.

The amount of MGa that is necessary for neutralizing the pollutants will depend on the pollutant mass, the degree of its excess APC and also the geoecoprotective activity A_{gep}.

Pollutants are converted into a soluble form (heavy metal ions) during the passage of precipitation in the form of rain and melted snow through this mixture and reacts with MGa. In this case low-solubility compounds are formed, which are safe for the environment.

Thus, a new approach to solving the problem of crushed ballast cleaning not only from suspended solids, but also from such super-toxicants of the XXI century as heavy metal ions will protect the soil from pollution in railroad precinct.

5. Conclusions

The proposed construction and technological solutions are based on the progressive experience of geosynthetic materials use for stabilization of roadbed operating zone of domestic and foreign roads. Also they are based on the technologies and means of mechanization available in the arsenal of Russian railways.

Railway track performs a key role in the economic growth of the country. The application of these solutions allows him to carry out not only transport, but also geoecoprotective function. This will lead to a favorable human, animals and plant environment by combining geoenvironmental technology with the railway track repair.

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