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Soling in Transport Construction Technologies

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Abstract: This study addresses the problem of environmentally friendly technologies in the transport construction. The study presents 3 technologies based on the silica sol properties: sol-gel transition, formation of heavy metal silicate hydrates; absorption of sols by capillaries and pores in concrete. Silica sol improved the concrete properties by 20-90%. The thermodynamical method is suggested to understand the nature of such improvements. Soil strengthening and detoxification appear rather promising outcome of the suggested technologies. Findings of this study can be useful for the purposes of environmental protection, soil strengthening and quality improvement in the transport construction.

Key words: Soling, soil detoxification, soil strengthening, transport, system, concrete

INTRODUCTION

At present, new construction technologies are expected to use environmentally friendly substances to manage the building material properties. One of the purest substances in the lithosphere is SiO_2 in the form of silica sol $SiO_2 \cdot nH_2O$. The previous studies addressed the problem of silica sol usage (Svatovskaya *et al*., 2010, 2014, 2015, 2016a-d). Silica sol has very useful properties in terms of environmental protection because it consists of SiO_2 and H_2O, both being safe natural substances.

This study presents 3 technologies of silica sol usage in construction for the transportation sector. The technologies are based on the silica sol properties: sol-gel transition, formation of heavy metal silicate hydrates, absorption of sols by capillaries and pores in concrete.

Hence, it is suggested to use the silica sol solutions in the transportation sector, taking into account the sol properties shown in Table 1.

The SGT is based on the transition $SiO_2 \cdot nH_2O$ (sol)→$SiO_2.nH_2O$ (gel) and gel's binding properties that are described by Svatovskaya *et al*. (2016a-d), Svatovskaya (2016a, b). They appear useful for sub-soil strengthening and other environmental protection measures, for example, silica sol can be used to detoxify the soil from heavy metals due to its binding properties. It makes the SDT an appropriate technology for the soil detoxication and it can be applied as a method of the environmental protection of soils (Svatovskaya *et al*., 2016a-d; Cheremisina *et al*., 2002; Myakin *et al*., 2011; Korsakov *et al*., 2007; Sychov *et al*., 2005). The SAT is based on the absorption characteristics of the capillary-porous materials. This technology can improve the technical properties of concrete. The surface pores and capillaries make the interaction with silica sol possible and as a result, calcium silicate hydrates form (Sychov *et al*., 2008, 2013, 2014; Bakhmet'ev *et al*., 2010; Myakin *et al*., 2014, 2016). The possibilities of the SGT, SAT and SDT technologies are shown by means of the thermodynamical method and the experiments.

MATERIALS AND METHODS

The calculations based on the thermodynamical method for the SAT and the SDT are given in Table 2 and 3. Apparently, the reactions are possible because of the negative meaning of the Gibbs energy. Table 2 demonstrates using the Ca(II) ions for the calcium silicate hydrates formation. The ions are important for both soil and artificial mineral stone strengthening. In the latter case, the sol solution is absorbed by the surface capillaries and pores of the artificial stone.

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Table 1: Sol-based technologies for construction in the transportation sector

Examples of sols	Processes in inorganic systems	Technologies for sub-soil construction
$SiO_2 nH_2O$	Sol-Gel Transition (SGT)	Soling for sub-soil strengthening due to binding properties of the gel
$Al_2O_3{\cdot}nH_2O$	Sol Absorption Technology (SAT)	Soling to improve concrete properties
$Fe_2O_3{\cdot}nH_2O$	Sol Detoxification Technology (SDT)	Soling for the environmental protection of soils against heavy metal ions

Table 2: Thermodynamical calculation of the reactions with Ca(II)

Ions	Reactions	ΔG^0_{298} (kJ of the reactions)
Ca(II)	$6Ca^{2+}+6(SiO_2{\cdot}H_2O)+12OH^- = 6CaO{\cdot}6SiO_2{\cdot}H_2O+11H_20$	-740·89
Ca(II)	$Ca^{2+}+2(SiO_2{\cdot}H_2O)+2OH^- = CaO{\cdot}2SiO_2{\cdot}2H_2O+H_2O$	-201·65
Ca(II)	$6Ca^{2+}+3(2SiO_2{\cdot}3H_2O)+12OH^- = 6CaO{\cdot}6SiO_2{\cdot}H_2O+14H_2O$	-284·89
Ca(II)	$Ca^{2+}+2SiO_2{\cdot}3H_2O+2OH^- = CaO{\cdot}2SiO_2{\cdot}2H_2O+2H_2O$	-50·65

Table 3: Thermodynamical calculation of the reactions with Cu(II) and Pb(II)

Ions	Reactions	ΔG^0_{298} (kJ of the reactions)
Cu(II)	$2Cu^{2+}+SiO_2{\cdot}H_2O+4OH^- = CuO{\cdot}SiO_2{\cdot}2H_2O+Cu(OH)_2$	-56.7
Cu(II)	$2Cu^{2+}+SiO_2{\cdot}2H_2O+4OH^- = CuO{\cdot}SiO_2{\cdot}2H_2O+Cu(OH)_2+H_2O$	-6.8
Pb(II)	$5Pb^{2+}+SiO_2{\cdot}H_2O+10OH^- = Pb(OH)_2+4PbO{\cdot}SiO_2+5H_2O$	-529.9
Pb(II)	$3Pb^{2+}+SiO_2{\cdot}H_2O+6OH^- = Pb(OH)_2+2PbO{\cdot}SiO_2+3H_2O$	-355.9
Pb(II)	$3Pb^{2+}+SiO_2{\cdot}2H_2O+6OH^- = Pb(OH)_2+2PbO{\cdot}SiO_2+4H_2O$	-395.9
Pb(II)	$3Pb^{2+}+2SiO_3{\cdot}3H_2O+6OH^- = Pb(OH)_2+2PbO{\cdot}SiO_2+4H_2O+SiO_2{\cdot}H_2O$	-202.9

Table 4: Application of SAT to concrete

	Improvement of properties (Δ%)				
Concrete grade	Compressive strength (+Δ)	Bending strength (+Δ)	Water absorption (-Δ)	Abrasion (-Δ)	Cold resistance cycles (+Δ)
B15, B20, B25, B30	15-30	20-35	50-65	20-30	75-90

Table 5: Soil detoxification of heavy metal ions

Heavy metal ion	Tolerable concentration of heavy metal ions in soil (TC, mg/g)	Solubility product of final substances (hydroxides and silicates)	Results of soil detoxification of heavy metal ions
Cu(II)	3.0	$<1.6\ 10^{-19}$	Detoxification occurred at TC above 1000 mg/g
Ni(II)	4.0	$<2.0\ 10^{-16}$	
Zn(II)	23.0	$<5.10^{-17}$	

RESULTS AND DISCUSSION

Sol solution has the following parameters: SiO_2-30.5%; Na_2O-0.35; pH-10.2; d-.2 g/cm^3, grain size-12 nm. For the SAT, concrete of the following grades was used: B15, B20; B25, B30. For the SGT, the sand-dust was used for strengthening that it is important for construction of railway embankments. For SDT, the sand with heavy metal pollutants was used.

The results of applying the SAT for concrete are shown in Table 4. The concrete samples were sunk in the 3% solution after 3 days of hardening, then in 28 days the main properties were tested using common methods.

For the SGT, 30% sol solution and dust-sand were used. The sand was saturated with the sol solution and after a few days of sol-gel transition, the surface of the sand was compact and stable against wind (however, not dust storm). If the sand is polluted with heavy metal ions (model experiment with tolerable concentrations of 500-1000 mg/g), it is possible to detoxify it. According to the experiment, samples of the polluted sand and the sand after soling were tested by the selected electrodes. The tested sand after soling showed no presence of the heavy metal ions.

The results show a possibility to affect sand soil and concrete by means of soling. The results of SDT analysis are given in Table 5. The thermodynamical calculations (Table 3) confirmed that the detoxification occurred.

Table 5 demonstrates that the substances of the reactions given in Table 3 have very low solubility product and, therefore, it is possible to detoxify the soil from the heavy metal ions. The SAT is practical for improving the properties of the transport constructions (Table 4 and 5). At that, the improvement of the concrete properties (Table 4) may be connected with the calcium silicate hydrate formation which is possible thermodynamically (Table 2).

CONCLUSION

Three sol-based technologies were presented in this study-gel transition, sol absorption technology and sol detoxification technology. It was thermodynamically and practically demonstrated that the properties of transport constructions can be improved by means of soling. The studied properties improved by 20-90%. Findings of this study can be useful for the purposes of environmental protection, soil strengthening and quality improvement in the transport construction.

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