INFLUENCE OF SELECTED CHEMICAL OR NANOCHEMICAL ADDITIVES (COMBINED WITH CEMENT) AND ALTERNATIVE HYDRAULIC BINDERS FOR TREATMENT OF LOCAL SOILS ON COMPRESSIVE STRENGTH

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ABSTRACT

The paper focuses on alternative solutions for processing locally available conditionally suitable soils treated by new types of binders or by selected chemical or nanochemical additives, which improve cement based soil treatments. It will be shown how new binders and selected additives can change final properties of stabilized soil materials used for pavement base layers or subgrade improvements. The paper focuses on assessment of these treated materials by means of traditionally applied test methods and requirements given in Czech technical specifications. Treated soils were tested with respect to required parameters for their future application in pavement structures – primarily utilized in base layers respecting the climatic zone and conditions in Central Europe. The tests performed were compressive strength after 7, 14, 28 and 60 days of curing and cyclic test of resistance to water and frost. All tests were performed on two types of soil (sandy, clay) with different dosage of used binders.

Keywords: Alternative Hydraulic Binders, Compressive Strength, Nanochemical Additives, Water and Frost Resistance

I. INTRODUCTION

The economic parameters of a construction project still remain one of the determining aspects of road construction work. At the same time, more and more emphasis has been put on improving the non-renewable resource exploitation recently, including the use of less suitable but locally available materials; we have focused intensely on the project’s impact on the environment, carbon footprint generation during construction and other aspects that were not usually as significant in the evaluation of construction structures and projects. The trend has been noticeable and, for a number of years, developed primarily in relation to reuse of materials incorporated in the pavement; materials that used to be classified as unsuitable for further processing, or materials we used to consider as waste materials even not so long ago. This paper pays attention primarily to the processing of unsuitable and conditionally suitable soils, using new (alternative) binders and additives to modify the traditional methods of soil treatment and stabilization by hydraulic binders. In the recent years, additives have been encountered which modify the hydraulic binder setting process or change the parameters of the soil used, thus allowing to process local materials even under extreme conditions when such materials would have been ruled out of application in the pavement structure otherwise. The new technologies have been embraced particularly in developing countries where good-quality road construction materials are scarce and, therefore, exploitation of on-site materials is desirable. It is currently striven to utilize such modern technologies in the conditions of the Czech Republic where alternative binders and chemical additives are applied to locally available soils that are presently classified as unsuitable, or conditionally suitable for further processing (usually due to a higher proportion of clay particles). Thus we try to change the existing soil treatment technology by hydraulic binders, particularly the commonly available Portland cement or slaked lime. The process of soil treatment by hydraulic binders has been known in the Czech Republic since the 1960's. The modification is presently used mostly for soils the mechanical physical properties of which fail to meet the requirements for processing within the pavement structure and which, therefore, must be modified, or replaced by a more suitable new material first. This process is always more demanding both economically and in terms of time.

The current standard (ČSN 73 6133) distinguishes the soils which are suitable or unsuitable as construction materials, or determine the cases where the soils cannot be used as a construction material. Unfortunately, the standards do not reflect the option of applying new, alternative technologies which facilitate economical processing of even extremely unsuitable soils. Theoretically, there are no obstacles for processing almost any sort of soil; the modification of unsuitable soils by hydraulic binders has been perceived as too expensive so far and, in most cases, the soil is removed and replaced by a more suitable new material. However, this is changing under the increasing pressure for recycling and implementation of new technologies to allow processing even materials that would not have been possible to use in the past.

II. MODIFYING ADDITIVES AND HYDRAULIC BINDERS

Modern alternative binders and additives focus not only on improving the existing methods but also on implementing completely new technologies which allow processing a broader range of materials. Alternative binders or selected chemical additives have several modes of operation. The first one is modifying the chemical environment of the material processed, the soil in our case, to make the material economical for further modification by standard hydraulic binders. Another option is modifying the hydration process as such to eliminate the effects of any undesired substances present in the soil. This results in modified final properties of the structure where higher strengths and improved resistance to frost and water are achieved. Two foreign additives, TerraSil and UPD, were selected for the comparison; they primarily prevent water from entering the structure, i.e. make the soil hydrophobic. Also Doroport, a Czech originating slow-setting hydraulic road binder the composition of which decelerates the increase of strength characteristics in time, was tested; the experimental study also included a ternary binder, Sorfix, which is developed in the Czech Republic by the Czech Technical University in cooperation with the Czech power company (ČEZ). As usual, a mix with no additives bound solely by cement was chosen as the reference mix. The project aimed to verify the expected (or, in other cases, declared) benefits of the individual additives in the conditions of the Czech Republic.

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2.1 TerraSil [1,2]

This substance is a nanotechnological, water-soluble, 100% organic chemical additive. The benefit of the additive can be seen particularly in hydrophobization of the mix where the resulting layer is highly resistant to water infiltration or not; this results in improved technical design parameters of the treated soil, particularly in case of frost and water susceptibility. The siloxane bond (Si-O-Si) facilitates the formation of a very thin, permeable membrane on the surface of soil particles, which is stable and chemically resistant while serving as waterproofing solution at the same time.

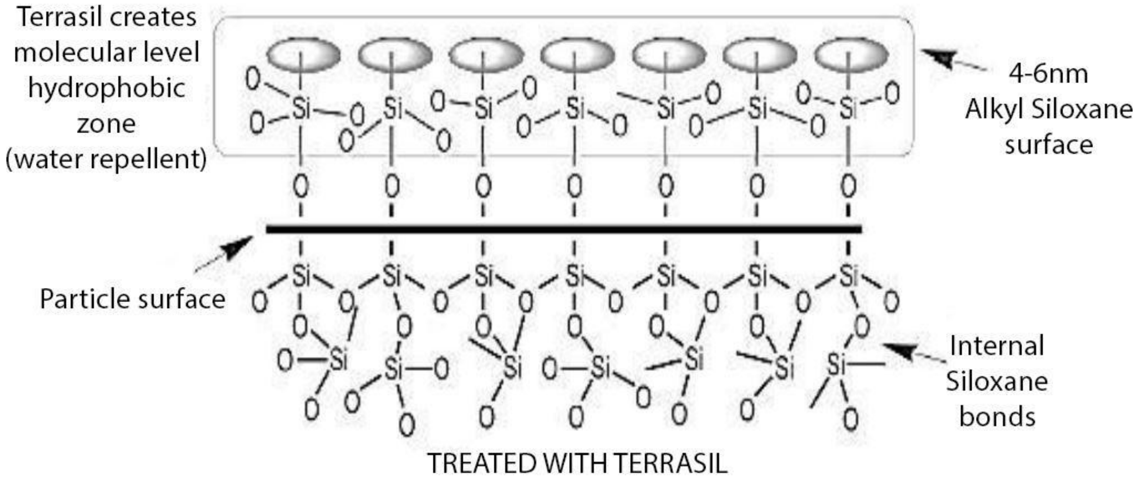

Figure 1: Surface treated by TerraSil [1]

This type of modification is possible for most soil types. The additive itself is mixed with water and, most often, applied to the compacted pavement surface which it impregnates, thus rendering the surface hydrophobic. The other option is mixing a diluted solution of the additive with the soil; in this case, the entire layer rather than just the surface is treated.

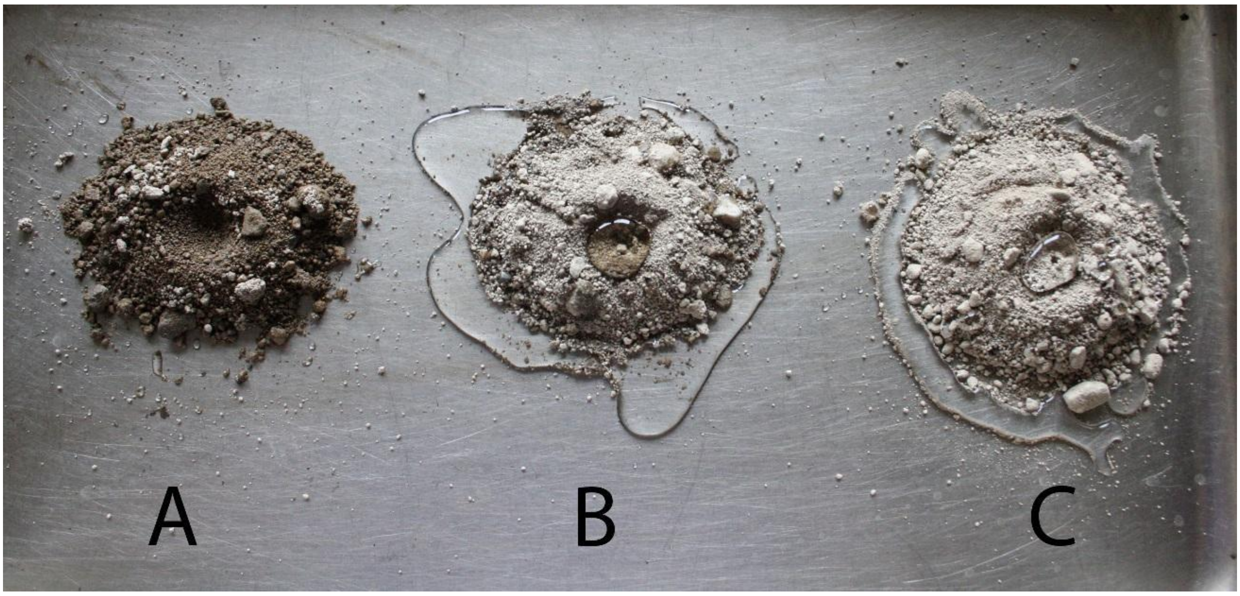

Figure 2: Mixture treated by Cement 3% and TerraSil A) 0% B) 0,01% C) 0,1%

2.2 UPD [3,4]

This is a liquid additive working together with cement. Through ion exchange, it neutralises any undesired chemical environment in the soil while preventing water from entering the pavement structure. This allows processing even chemically polluted soils when leaching of harmful substances into the environment is prevented. A typical example is treating soils polluted by fuel, oil, lubricants and other undesired petrochemical substances which occur on the sites of old warehouses, industrial premises, airports etc. Such soils are currently handled as dangerous waste; according to the applicable legislation, they must be removed and stored at special landfills which is rather costly. Layers bound by UPD can be used most often in the pavement base and subbase. The improved resistance to cracks and propagation thereof to upper structural layers of the pavement as declared by the manufacturer is also a significant advantage. Higher cement content can be used without the need for providing expansion joints which are always a problem point in any structure (especially if found in the base and subbase). The additive declares the ability to process a broad range of soils; the only limit in this case is organic substances contained in the soil – these should not exceed 5 % which corresponds with the current recommendations of European standards. The additive is added straight in the mixing drum of the milling machine along with water.

2.3 Georoc Doroport TB25 [5]

This is a road binder type adjusted specifically to the conditions in the Czech Republic. The additive is a powder constituted by a suitable combination of ground clinker and hydraulic binders, developed for road construction purposes. It is currently used most often in base and subbase layers for soil stabilisation and improvement. Main advantages of Doroport include high resistance to sulphates, extended period of mix workability and a major benefit is the slower strength increase in time. The gradual binder hydration helps eliminate the possibility of shrinkage cracking and the binder proportion in the mix can be higher. A material advantage in CZ is the existence of practical experience where Doroport is perceived as a full-fledged tool for soil treatment. Like other hydraulic binders, Doroport is most often spread over the surface of the soil to be treated and a milling machine is used to mix it with the soil.

2.4 Ternary Binder - Sorfix

A ternary binder based on various types of fly ashes was developed in CZ based on fly-ashes typical for this country. The binder composition is covered by a patent. The binder is currently going through a further development stage. A sample was obtained within the framework of the CTU Prague research project. Most often, the combination involves cement and other components, in this case fly ashes from coal-burning power plants where the main effort is recycling the waste material while using it as a valuable binder for structures in road construction.

III. EVALUATION OF THE DECLARED CHARACTERISTICS

The practical part of the project focused on the treatment of two types of soils and subsequent evaluation thereof. The concerned soils were classified, according to the currently applicable national standard (ČSN 73 6133), as sand with a proportion of fine-grained loamy particles (S-F) obtain from section 9 of the modernisation of main Czech motorway D1 on the 72nd km, as well as clayey sand (SC) extracted at the construction site of the 3rd railway corridor in Veselí nad Lužnicí, Czech Republic. Depending on the soil classification, CBR and identified optimum moisture content, the quantity of the hydraulic binder was set to 3 % for the sand with a proportion of fine-grained soil and 6 % for clayey sand. The contents of the additives, UPD (0.15 l/m^3 of soil) and TerraSil (0.01 % per 100 % soil) which are most often added in combination with cement were determined on the basis of previous findings and technical consultations. In the case of Doroport hydraulic binder and Sorfic ternary binder, the contents were chosen on the basis of the quantity of cement applied to the reference mix to allow comparing the variants to one another.

3.1 Compression Strength

Compression strength and resistance to frost and water immersion were selected for the purpose of verifying the declared properties of the additives; this is in accordance with the current requirements of European standards EN 14227-10 Hydraulically bound mixtures – Specifications – Part 10: Soil treated by cement. Specimens were prepared on a Proctor compactor in compliance with standard EN 13286-50 Unbound mixtures and mixtures bound by hydraulic binders, Part 50: Methods for test specimen preparation by Proctor compactor or vibration plate. Compression strength was measured after 7, 14, 28 and 60 days, specimen classification is governed by the aforementioned standard EN 14227-10 while observing the slenderness ratio of 0.8. Freezing occurred during 13 cycles under the temperature of -20 +/-21 °C.

Table 1: Strength characteristics of sand with a proportion of fine-grained loamy particles

Cure	3% cement	3% cement+ 0,1% Terrasil	3% Doroport	3% cement+ UPD	3% Sorfix
	compressive strength				
7 days	2,89	2,13	2,27	2,52	0,20
14 days	3,22	2,74	2,54	3,09	0,38
28 days	3,14	3,39	2,83	3,07	0,68
60 days	4,28	3,24	3,60	3,66	1,05
resistance to water and frost	1,66	2,73	1,59	2,34	0,28
	52,85%	80,59%	56,22%	76,21%	28,04%

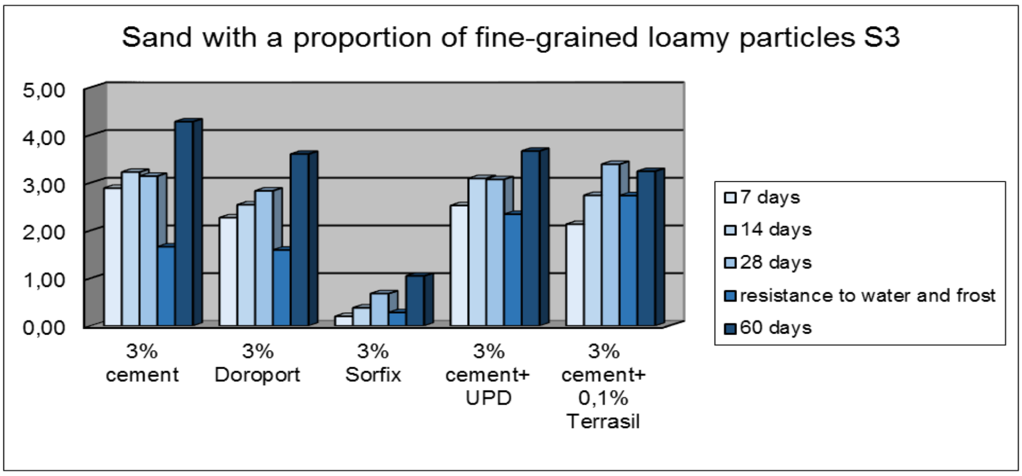

Figure 3. Strength development in time for sand with a proportion of fine-grained loamy particles

The values measured for sandy soils with fine-grained loamy components clearly demonstrate the benefits of TerraSil and UPD which focus primarily on hydrophobization of the mix where the treated mix has a better resistance to water in the structure, and should prevent water from entering the individual grains at all. The fact was confirmed during the test of resistance to water and frost where the specimens treated by TerraSil showed roughly 30 % higher strength than the reference mixes bound solely by cement. In the case of UPD, the improvement was roughly 25 % against the reference mix. Also a slower but constant increase of strength in specimens bound by Doroport was observed. The application of the ternary binder appeared to be absolutely unsatisfactory when, compared to cement, the binder demonstrated significantly lower compression strengths and failed to meet the requirements for water and frost susceptibility.

Table 2: Strength characteristics of clayey sand

Cure	6% cement	6% cement+ 0,1% Terrasil	6% Doroport	6% cement+ UPD	6% Sorfix
	compressive strength				
7 days	3,24	3,25	3,13	3,78	1,74
14 days	4,06	4,75	4,25	4,77	1,79
28 days	3,69	4,36	6,07	5,78	2,05
60 days	4,87	7,24	6,55	8,90	2,34
resistance to water and frost	3,93	4,33	5,24	4,67	0,30
	106,50%	99,45%	86,42%	80,84%	14,57%

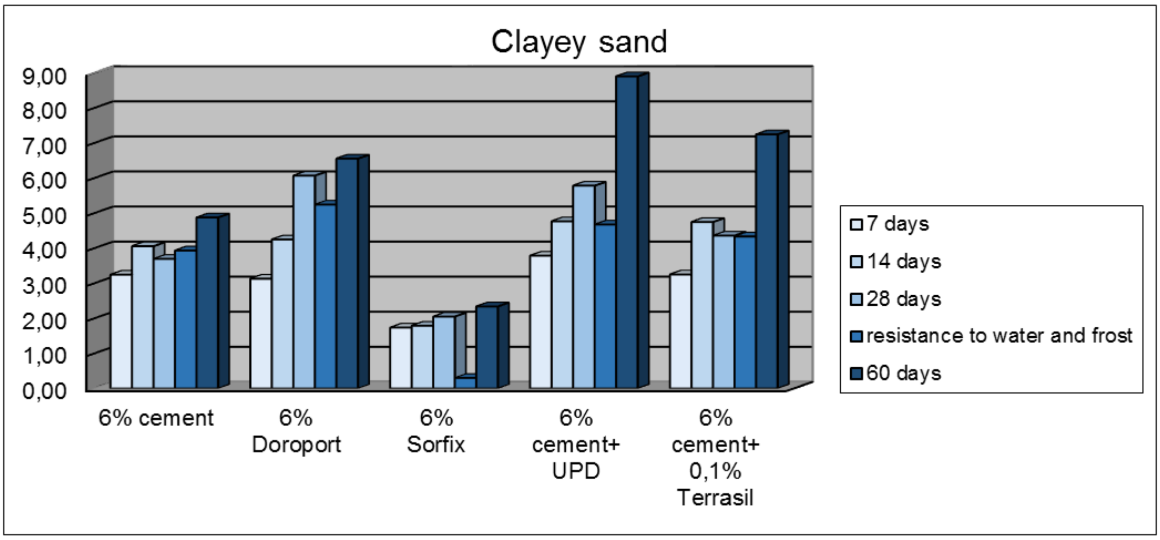

Figure 4. Strength development in time for clayey sand

The strength characteristics measured for treated clayey sand rather corresponded with the predicted behaviour of individual additives. Thanks to the high doses of the binders applied to the mixes, the reference mix showed partial decreases of strength. This phenomenon is probably caused by the too rapid strength increase in time and the occurrence of micro-cracks associated with the hydration heat release. A similar problem also occurred in the case of the mix treated by TerraSil where the additive focuses primarily on improving water susceptibility of the mix. From the point of view of resistance to water and frost, all specimens (with the exception of the samples bound by the ternary binder) met the applicable European standards. What is still surprising is the increase of strength in the reference mix where the strength after freezing exceeded the strength after 28 days. Compared to the other additives, the strength measured for the reference mix were ten times lower. The slow-setting road binder, Doroport, proved its potential again when the strength of the other soil increased constantly, too. Even for the other soil, the mixes bound by the ternary binder were shown to be unsatisfactory when a significant impact of water on such mixes was proven again.

IV. CONCLUSION

With the increasing requirements for construction structures and economical aspects, environmentally compatible approach to construction thereof, modification of the existing soil treatment technologies presents a viable solution. This paper points out some of the possible alternative soil treatments by hydraulic binders where modern additives show a significant potential. For TerraSil and UPD, the impact on mix hydrophobization was verified where the additives showed a positive effect on resistance to frost; the impact on cement hydration as such where the additives had a beneficial effect on strength characteristic development in some cases was of interest as well. Prior to any possible practical use, it will be desirable to verify the effect of the additives on any specific soil types. The slow-setting hydraulic binder Doroport met the expectations and its contribution was proven even with higher doses of the binder when the mix did not degrade due to micro-cracks. Further, Doroport-treated mixes showed a slower but constant increase of strength in time. The results were also stable with respect to all parameters measured for both soil types. The ternary binder was observed to be unsuitable for fine-grained soil modification where a major role plays the water absorption power of the soil itself which cannot be influenced by the binder at all. Compared to the other binders, the specimens bound by the ternary binder demonstrated minimal improvements of strength characteristics in comparison to unmodified soil. This option failed to meet the requirements for resistance to frost and water completely. The binder is extremely unsuitable for fine-grained soil treatment; it will not be included in any further experimental work in its present form. In the future, the portfolio of the modified soils will have to be expended to allow more thorough evidence of the declared benefits of the individual additives. Similarly, it seems beneficial to obtain more additives and binders for a broader comparative test.

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