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# PHYSICAL PROPERTIES AND LONG TERM STABILITY OF STABILIZED CONTAMINATED SOIL

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## ABSTRACT

By far, Finnish authorities have applied Dutch procedures when accepting stabilization as a remediation solution. However, the local conditions should play an important role when quality standards are given. In this study one of the main interests was to evaluate the long term properties of stabilized materials in the harsh climate conditions. The investigated material (As, Cr, Cu contaminated) was sampled from the surface layer of an old impregnation plant in Eastern Finland. The binding agents used in stabilization were ordinary Portland cement, fly ash and gypsum. The mixes with different binding agents were planned to achieve two different compressive strengths, 5 MPa and 1 MPa. The compressive strength results indicated a slower early strengthening speed with the samples containing fly ash or gypsum. The measured water permeabilities varied between the values of $10^{-7}$ and $10^{-5}$ m/s. The results from the pore size distribution measurements showed a rather large amount of gravitation pores 20...30 % which result supports the rather large water permeability. The long term stability of samples were tested with freeze-thaw test (ASTM D 4842). A Finnish standard (SFS 5447) for testing the freeze-thaw resistance of concrete specimens was also used. The ASTM-freeze-thaw test results indicated that the samples of low compressive strength didn´t withstand the stress as well as the firmer samples. All the samples were partially destroyed in the SFS freeze-thaw test.

## INTRODUCTION

In Finland there are several old saw mills and wood impregnation plants where the soil is contaminated by arsenic, copper and chromium. These contaminated sites are often situated on groundwater areas wherea grounwater is situated under postglacial gravel and sand deposits with large water permeability. There is a urgent need to isolate the contaminant from the surrounding environment either by stabilization or by other remediation methods.

Stabilization with the cement based binder agents is the most common remediation method for inorganic contaminants in soils. Obviously the utilization of stabilization is based on physical encapsulation and chemical fixation of contaminants allthough there are several different theories discribing the binding mechanism of contaminants in cement matrix (Cocke[1]). The utilization of fly ash and waste gypsum as binder agent in stabilization is can be done for economical reasons to replace the more expensive binder agent cement. But also there usage of fly ash can decrease the leachability of heavy metals from stabilized materials by decreasing the pH value of the cement matrix (Cote[2]). The most important physical properties of stabilized soils are low water permeability and sufficient compressive strength. The values of compressive strengths mentioned in the literature vary in the large range from 0.1 MPa to 10 MPa

In Finland the weather conditions are rather hard compared to most parts of Europe. The utilization of stabilization in our climate conditions should be tested before the remediation project is done. The purpose of this research project was to evaluate the physical properties of stabilized contaminated soils and also evaluate the long term resistance of stabilized samples against freezing and thawing using different standardized methods. One of the main interests was to evaluate the effect of different compressive strengths on physical properties and long term stability.

## MATERIALS AND METHODS

The contaminated soil was originally from a surface layer of an old impregnation plant in Eastern Finland. The soil was contaminated by a impregnation agent contaning arsenic, chromium and copper. The average amounts of these contaminants were 650 mg/kg for As, 480 mg/kg for Cr and 590 mg/kg for Cu. The average pH value of the material was 5.4. The total amount of soil delivered to our laboratory was 1000 kg. The equal quality of the material was guaranteed by controlled cross mixing method using a large laboratory mixer. During the mixing it was noticed that the contaminants were concentrated to a certain "hot spots" which couldn't be broken totally during mixing. The soil contained also small parts of wood. The grain size distribution of the soil sample is presented in Figure 1. The average grain size of the contaminated soil was 0.45 mm and the amount of fine fractions (<0.074 mm) was 4 %. According to the Finnish soil classification the material was determined as sand.

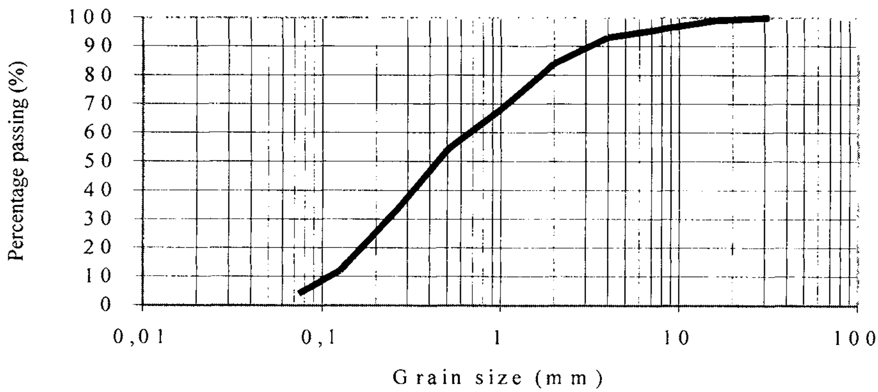


Fig. 1. The grain size distribution of the contaminated soil

The binder agents used in stabilization were Ordinary Portland cement, fly ash and a mixture of calcium sulfate and fly ash. The fly ash was originally from a coal burnig power plant and the gypsum came from a suplhur refining process of a power plant, gypsum was calcinated at 200 °C before the use. The amount of binder agent and water was evaluated according to the Finnish standards for soil-cements mixtures. The mixtures were planned to achieve certain compressive strength values at the age of seven days (1 MPa and 5 MPa). After the premium tests the amount of binder agent of 6 % was selected for 1 MPa samples and 9 % for samples of 5 MPa. The water binder ratio w/c was 0.8. The compressive strengths were measured at the ages of 7, 28 and 91 days. The total amount of samples prepared for this project was nearly 300. The test specimens were compacted with a gyratory compactor to a specific density of 90 % of the maximum proctor density.

The water permeabilities were measured by an equipment using changeable hydraulic gradient (2-4 m) in a measurement cell with flexible walls.

The mineral composition of the original and stabilized samples were analysed with a X-ray diffraction analyser. The main minerals of the contaminated soil were quartz, plagioglace, feldspar, hornblende and chlorite.

The pore size distributions were analysed by a mercury intrusion porosimetry. The chemical analysis of the samples and the leachability of contaminant are published later in other forum.

The long term stability of 91 days old specimens was tested in three different methods: according to ASTM standards for wetting and drying (D 4843[3] ) and freezing and thawing (D 4842[4] ) and also with a Finnish SFS[5] standard for freeze-thaw resistance of concrete specimens. Both ASTM tests contain 12 testcycles. The ASTM freeze-thaw test temperatures are -20 °C and +20 °. The results of the ASTM test are presented as a relative mass loss of tested specimen compared to control specimens. After our opinion the the 12 cycles of ASTM-test for wetting and drying is corresponding one summer in Finland.. The ASTM-test for freezing and thawing is corresponding one year in Finnish weather conditions if the stabilized material is uncovered. The SFS-test contains 100 cycles of freezing (-20 °C) and thawing (+30 °C). The SFS test corresponds rather harsh climate stress during several tens of years.

## RESULTS

The results of the compressive strength measurements are presented in Table 1. The specific density of all the samples was on average 1,9 g/cm$^3$ and the moisture content was on average 4 %. The measured strengths were slightly higher than those that were originally planned. The early compressive strengths of specimens with fly ash or gypsum were smaller than the values detected with pure Portland cement. The hydraulic reactions are starting slightly slower when fly ash or gypsum are used. When the curing time increased to 91 days the compressive strengths reached the same level as with Portland cement. The amount of binder agent clearly controlled the level of the compressive strength.

Table 1. The compressive strengths of the stabilized specimens at the ages of 7, 28 and 91 days.

| Sample | Compressive strength at the age of 7 days (MPa) | Compressive strength at the age of 28 days (MPa) | Compressive strength at the age of 91 days (MPa) |
|---|---|---|---|
| C6 | 2,15 | 2,28 | 1,90 |
| C9 | 4,85 | 4,81 | 5,32 |
| C6FA20 | 1,22 | 2,05 | 1,90 |
| C9FA20 | 4,08 | 4,47 | 5,67 |
| C6FA10G10 | 1,02 | 1,36 | 2,10 |
| C9FA10G10 | 3,54 | 4,26 | 4,23 |

C6 - the amount of binder agent (cement) is 6 %
FA20 - 20 % of the binder agent is fly ash
G10 - 10 % of the binder agent is gypsum

The water permeability test results are shown in Table 2. The water permebilities varied between $10^{-5}$ and $10^{-7}$ m/s. Obviously the organic wood pieces and also the unbroken contaminant hot spots are increasing the water permeability values. The porosity results are also showing a rather large amount of gravitation pores which clearly indicate a large water permeability. The total porosity measured by mercury porosimetry varied from 20 to 30 %. A smaller amount of pores was detected with the samples having higher compressive strength. The amount of gravitation pores (diameter > 10 μm) was on average 60 % when the amount of binder agent was 9 % and 80 % when the amount of binder agent was 6 %.

Table 2. The water permeabilities of specimens at the age of 91 days.

| Sample | Water permeability (m/s) |
|---|---|
| C6 | $2.5*10^{-5}$ |
| C9 | $2.0*10^{-5}$ |
| C6FA20 | $2.2*10^{-5}$ |
| C9FA20 | $1.2*10^{-6}$ |
| C6FA10G10 | $6.8*10^{-6}$ |
| C9FA10G10 | $7.0*10^{-6}$ |

The results from the ASTM wetting and drying test showed that during the test no remarkable changes was noticed the samples were as firm as before the test. The mass loss of the specimens were under 1 %. The relative mass losses during the ASTM freeze-thaw test are shown in Table 3. The maximum weigth loss during the test was 10 %. The results indicate clearly that the resistivity of samples containing 6 % of binder agent is weaker than the resistivity of samples contaning 9 % binder agent. During the test the changes in sample structure was also noticed (Fig 2). The SFS freeze-thaw test results (Fig 3) indicate a partial collapse of the sample structure.

Table 3. The relative loss of mass during the ASTM D4842-90 freeze-thaw test.

| Sample | The relative loss of mass (%) |
|---|---|
| C6 | 5.04 |
| C9 | 0.28 |
| C6FA20 | 9.81 |
| C9FA20 | 0.25 |
| C6FA10G10 | 10.23 |
| C9FA10G10 | 0.2 |

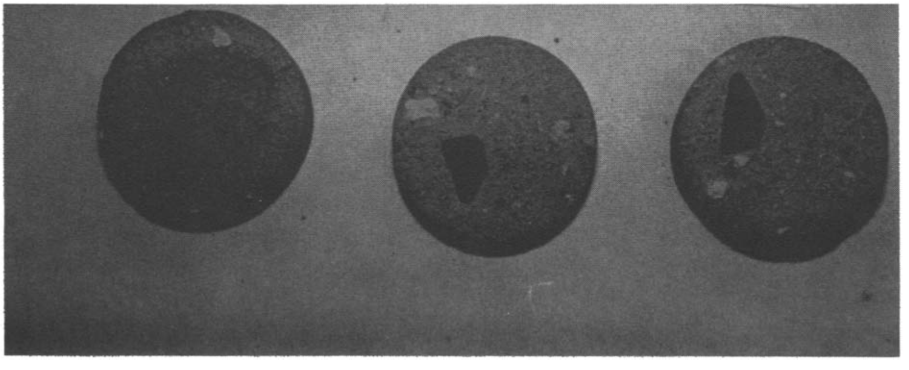

Fig 2. Specimens after the ASTM D4842-90 freeze-thaw test.

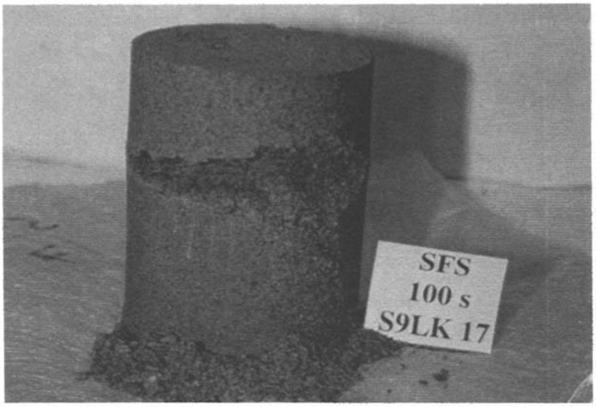


Fig 3. A sample after the SFS freeze-thaw test.

The X-ray diffraction analysis showed that the samples contained ordinary cement minerals no prove was found of mineral compounds containing Aa, Cr or Cu. The chemical and minerological composition of stabilized materials will be tested more accurately in the future.

## CONCLUSIONS

The early compressive strengths of specimens contaning fly ash or gypsum as binder agents were lower than the values of those samples containing cement as binder agent. The compression strengths of all samples reached the same level after 91 days curing when the amount of binder agent was the same. The ASTM test for wetting and drying didn't show any changes in the sample structure and no differences between the samples. The ASTM test for freezing and thawing showed clearly that the samples with lower (1 MPa) compression strength had a lower resistance for freezing and thawing. Allthough after the literature (LaGrega et. al.[6]) the relative weigth loss of 15 % would be acceptable. On the other hand the ASTM tests are rather soft for Finnish weather conditions. The SFS standard test showed clearly that the samples cannot resist hard weather conditions. After our opinion the ASTM freeze-thaw test should be done for all materials used in stabilization.

The pore size distribution results and the water permeability results correlate well with each other. The pore size distribution test could be a premium test when stabilization mixture is planned.

The chemical leaching tests and more accurate structrural analysis for all the tested specimens will be done in the future.

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