ABSOILS – Sustainable Methods and Processes to Convert Abandoned Low-Quality Soils into Construction Materials

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ABSTRACT

The Absoils project demonstrates the utilisation of abandoned and low-quality soils in construction. The project is carried out in co-operation of Biomaa Oy, Rudus Oy and Ramboll Finland Oy. The project is supported by the cities of Helsinki, Espoo and Vantaa in the role of city developers/constructors and the Ministry of the Environment. The project is co-financed by the EU LIFE+ Environmental Policy & Governance programme (LIFE09 ENV/FI/000575). The project is located in the Finnish capital area where around 4 million tonnes of abandoned soils are generated annually. The project demonstrates beneficial ways to utilise clay and other abandoned soil materials from construction sites. The aim of the project is to decrease the landfilling of useful materials and to decrease the use of virgin material.

Abandoned and low-quality soils can be improved by stabilisation. The stabilising agents can be, for example, fly ashes, cement, lime, flue gas desulphurisation gypsum and other by-products. The amount of cement required for stabilisation can be diminished by the application of industrial wastes. Two pilot structures are presented in this article. The first pilot (Arcada II) is a stabilised "lightweight" filling with clay to enhance the stability of the area. The stabilisation in Arcada II was carried out in 2011. The second pilot (a dog park) will be built on a flooding area with low loadbearing capacity. The area is raised with clay filling, and the whole area will be stabilised in spring…summer 2012. The purpose of the project is to utilise surplus clay originating from adjacent construction sites. At least one more pilot application - not described in this article – will be made during the Absoils project. In the third pilot (Jätkäsaari) dredged sediments are stabilised in the Jätkäsaari area in Helsinki. It was partially conducted in 2011 and will be continued in 2012.

Keywords: Maximum of 5 keywords. Recycling & reuse of materials, Clays, Ground improvement, Industrial wastes, Laboratory tests

1 *PROJECT BACKGROUND*

All over the world vast amounts of excess soil are generated in construction sites when for example soils with low load bearing capacity are deposited in landfills and rock aggregate or gravel are transported for replacement. The abandoned soil material is traditionally considered to be of too low a quality to be used at the construction site. About 20 to 30 million tonnes of excess or abandoned soil are generated every year in Finland. In the capital area the amount reaches to about 4 million tonnes. Most of these excess soils are clay or other soft soils which are usually regarded as difficultly utilised, but can actually be used after stabilisation.

Annually, about 340 000 m^3 of unconta-minated clay and silt are transported to landfill sites and about 400 000 m^3 of rock aggregate is brought from elsewhere for replacement in the capital city, Helsinki. The city has currently exceeded its landfilling capacity and the neighbouring cities, Vantaa and Espoo have introduced a ban on receiving the abandoned soils from Helsinki. All this forces the city to increase the utilisation of the surplus soil materials.

The Absoils project aims at demonstrating ways to utilise abandoned clays and other soft soils in the construction sites. Figure 1 shows a common way of handling the low-quality soils originating from construction sites. This approach requires a lot of transportation which, among others, results in increased traffic and CO_2 emissions.

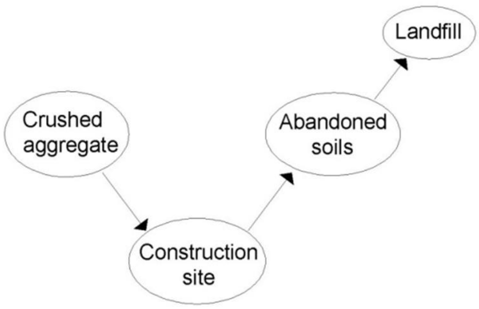

Figure 1. Common procedure for low-quality soils from construction.

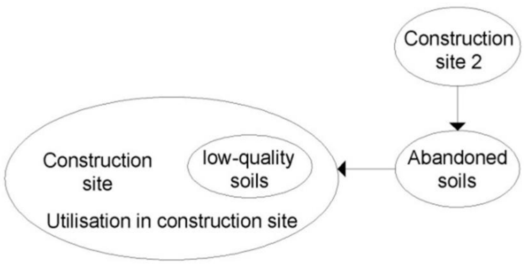

Figure 2. Alternative solution for the utilisation of abandoned soils.

The alternative solution which is promoted by the Absoils project is depicted in Figure 2. The alternative solution includes the utilisation of the low-quality soils at a construction site. However, if the utilisation at the construction site is not possible then the next best alternative is to transport the soils to a site that can utilise the soils or to a recycling centre where the materials could be modified for further use.

In the Absoils project abandoned soils are used in different types of applications, for instance a flood embankment or light-weight structure in order to demonstrate their various utilisation possibilities

During the project at least four pilot structures are constructed. In the following chapters two of the three pilots so far planned or carried out are presented along with the some results of the laboratory studies. The locations of the pilot applications are shown in Figure 3. Arcada II (chapter 3.) is marked as 1; Dog Park (chapter 4.) as 2 and Jätkäsaari as 3.

Figure 3. Location of the pilot sites.

The project also aims at producing information about the possible environmental impacts by carrying out the life cycle assessment (LCA), and about the financial impacts by studying the life cycle costing (LCC). It is assumed, that by utilising the abandoned soil materials, the environmental impact of the structure would be lower than in case of a more common structure. Also the costs of constructing and maintenance of the structure are assumed to be lower.

The ABSOILS project is coordinated by Ramboll Finland Oy, carried out in co-operation with the beneficiaries: Biomaa Oy, Rudus Oy and it receives advice from the members in the steering group; the cities of Helsinki, Espoo and Vantaa and the Ministry

of the Environment. The project is co-financed by the EU LIFE+ Environmental Policy & Governance programme (LIFE09 ENV/FI/000575). The project started in September 2010 and it will continue until December 2014.

2 LABORATORY TEST PROCEDURES

2.1 Stabilisation

Stabilisation is a procedure where material is enhanced by mixing the material with a binder agent. The binder agent reacts with the stabilised material forming bonds that enhances the compressive strength and modulus of the material.

The stabilisation agent is usually cement, but also industrial by-products or waste can be utilised in this process. In Absoils project the tested by-products are fly ashes, flue gas desulphurisation gypsum and another gypsum by-product.

The stabilisation properties of the clays are studied in laboratory by making specimens and studying the compressive strength of the specimen (diameter 42 mm and height 84 mm) after specified curing time. Unconfined compressive strength (1-axial) test is done according to the SFS 179-2 – CEN ISO/TS 17892-7:fi standard. Usually several different binders and binder amounts are tested to determine the most suitable binder mixture for the construction. All of the unconfined compressive tests are made with two similar specimens to out rule any quality changes.

2.2 Density control

Density control is not a standard procedure in stabilisation. In the Arcada II pilot the maximum allowed density (1500 kg/m^3) of stabilised clay was determined in the work specification. This kind of density control is needed only when stabilised clay is used as “light weight” material.

Stabilisation test specimens are made from the clays of which density is modified. Density control is performed by adding a determined amount of water to the sample which is then homogenised. The density of the clay is measured after the water addition, according to the standard CEN ISO/TS 17892-2:fi.

3 PILOT 1 – ARCADA II

3.1 Background information about Arcada II

First pilot carried out in the framework of the Absoils project was Arcada II where stabilised clay was used as a light weight structure. The structure was designed to replace an old embankment floating over a soft clay layer. A cross section of the embankment and the site is presented in Figure 4.

Arcada II is located in the Kyläsaari area in Helsinki (see the location in Figure 3). The area had low stability and load bearing capacity. The site was originally filled from the sea with blasted rock in 1960's. The original aim was to displace the existing clay with blasted rock to create a foundation for a new highway. However because of the deep clay layer and difficult circumstances the mass exchange failed leaving the blasted rock to float on top of the clay layer. The route of the highway was also changed and the area was left for secondary use for decades until 21st century when the development of the area has begun.

In the Arcada II the aim of the project has been to improve the area for construction use by removing contaminated soils, lightening the blast rock embankment, installing steel-pipe piles for a pile beam and plate structure on the road Kyläsaarenkuja area to stop the lateral expansion caused by the old embankment. In this case the Absoils project the focus has been on the construction stabilised “light weight” structure with abandoned clays brought to the Arcada II site form adjacent sites which cannot utilise those clays.

“Light weight” material means in this case that the stabilised clay was actually lighter than the existing blasted rock material, which was replaced ($\gamma'_{clay} \approx 5$ kN/m^3 and $\gamma'_{blasted\ rock} \approx 10\text{-}13$ kN/m^3 under water level). That is why the stabilised clay is called “light weight” material, although it does not fill the criteria set for the light weight material in standard SFS-EN 13055-2.

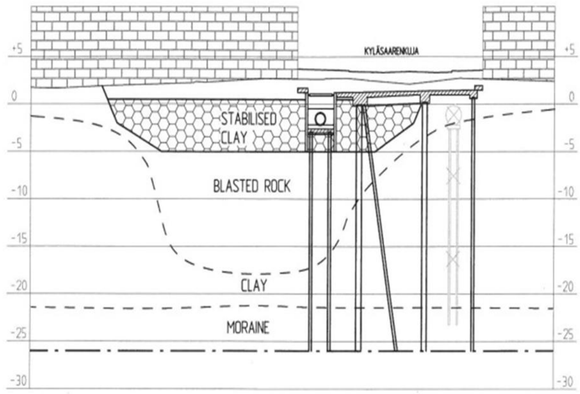

Figure 4. Arcada II cross sectional cut of the site with stabilised clay and steel-pipe columns.

In the Arcada II Absoils pilot the old structure material (blasted rock) was dug out from the floating embankment and abandoned clays were put to replace the rock aggregate. The density of the abandoned clays was decreased by adding water and the clays where stabilised on site with mass stabilisation machine. Mass stabilisation method is presented e.g. by Lahtinen & Niutanen (2009). Test stabilisation in the area was performed in December 2010 and the construction work was performed from April 2011 to the end of August 2011.

3.2 Laboratory testing of Arcada II

The light weight structure was made from abandoned clays which were stabilised by controlling and reducing the density of the soil. Before the stabilisation was done on site, the effects of water addition to density and to stabilisation properties were studied in the laboratory. After the density studies different binder materials were tested in order to find out how alternative binders such as fly ash works in the stabilisation. In the first phase of stabilisation testing, different binders were tested with only one clay sample. In the last part of laboratory stabilisation testing, different abandoned clays were stabilised with only one binder, which was chosen to be used on site, in order to find out the suitability of the materials for stabilisation.

3.2.1 Density control and its effects of compressive strength

The density control studies were made with nine (9) different samples according to the description in chapter 2.2. The results of the density control studies are presented in Figure 5.

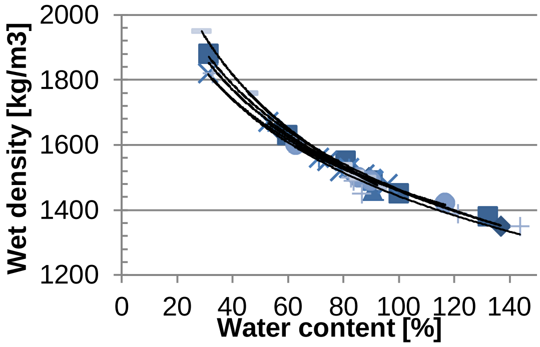

Figure 5. Density control studies.

The targeted wet density for the materials was 1500 kg/m^3 ($\gamma \approx 15$ kN/m^3). The results of the density control studies showed that the optimum water content for the studied abandoned soils was approximately 83–93 %.

The stabilisation properties of soils in different densities were also studied by making specimens of the soils in three different densities. The studies were made with one soil material and with two different binders. The binder options were cement (100 kg/m^3) and the mixture of cement and fly ash (FA) (cement 50 kg/m^3 and fly ash 150 kg/m^3). The results of the specimens can be seen in Figure 6.

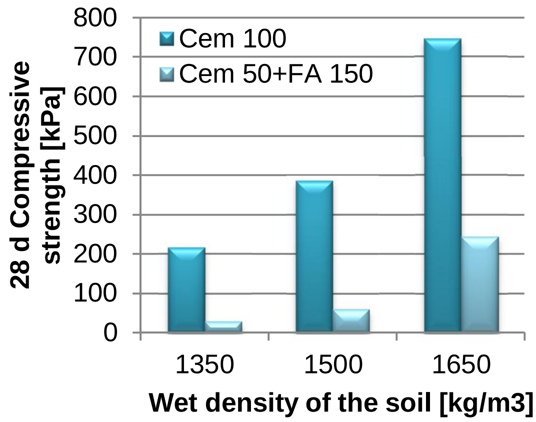

Figure 6. The effect of density to the 1-axial compressive strength (Cem=cement; FA=fly ash)

It can be seen in the figure that the density of the clay has a big impact on the compressive strengths. With higher density the water-binder ratio is lower and the compression strength is higher. The cement-fly ash mixture gave poorer results after 28 days of curing than the cement stabilised clays. The results show that raising the water content too high is dangerous and can lead to serious loss in compressive strength.

3.2.2 Testing of different binder options for stabilisation

The utilisation possibilities of alternative binder solutions were studied in the laboratory. The alternative binders were fly ash (FA) and flue gas desulphurisation gypsum (FDG). One abandoned soil material (clay) was used for the stabilisation studies and the targeted compressive strength was 100 kPa. The results of the stabilisation studies can be seen in Figure 7 and Figure 8.

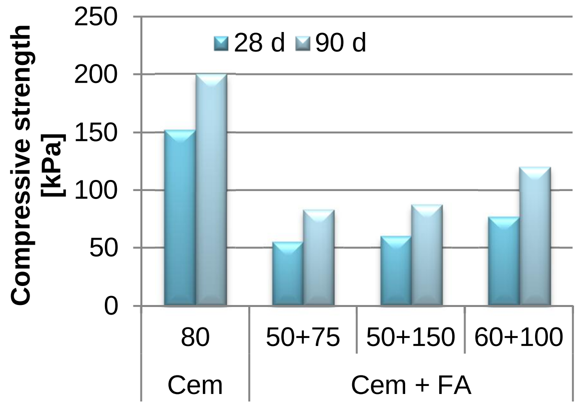

Figure 7. Compressive strengths with cement (Cem) and cement- fly ash mixtures (Cem + FA).

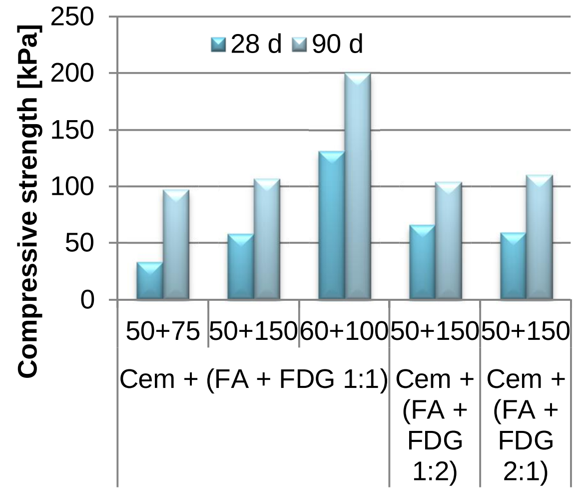

Figure 8. Compressive strengths with cement-fly ash-flue gas desulphurisation gypsum–mixtures.

The results from the stabilisation studies show that also with alternative binder options the targeted compressive strength can be achieved. The best alternative binder mixture was cement with fly ash and flue gas desulphurisation gypsum. The different fly ash-flue gas desulphurisation gypsum ratios (1:2/ 1:1 /2:1) didn’t have any effect on the compressive strength.

The utilisation of fly ash or flue gas desulphurisation gypsum as binder would have required an environmental permit. Because the schedule of the project was tight and the permit process is slow, there was not enough time to apply the permission meaning that the alternative binders could not be used in the project.

In case the fly ash or flue gas desulphurisation gypsum could have been used on the site the possible savings in the amount used cement would have been about 40 %, which would have meant about 1 300 tonnes of cement meaning about 120 000 € of savings in the binder costs.

3.2.3 Suitability of different clays for stabilisation

In order to find out if all of the available abandoned clays were suitable for the stabilisation with cement, the clays were tested in the laboratory. Several abandoned clays were tested as a single site cannot supply enough clay for the needs of the whole project.

In the tests the abandoned clays were stabilised with 100 kg/m^3 of cement in the 1500 kg/m^3 density. The results of the stabilisation tests of the abandoned clays are presented in the Table 1.

Table 1. Compressive strengths of stabilised abandoned clays.

Sample	Compressive strenght [kPa]	
	7 d	28 d
Koivukylä	< 10	< 10
Korpitie	101	127
Piloting site/basin 3	322	428
Korpitie area 4/1	583	747
Korpitie area 4/2	502	662

The compressive strengths of the stabilised clays varied a lot: from no strength development to compressive strengths of over 700 kPa. The Koivukylä sample had no strength development and was not used in the project. However, all the other samples reached the targeted compressive strength and could be used in the stabilisation.

On the basis of these results the stabilisation was performed with 100 kg/m^3 of cement and so that the density of the abandoned clay was adjusted to 1500 kg/m^3.

3.3 Construction process in Arcada II

The total volume of the stabilised abandoned clay was ≈32000 m^3, the surface area ≈7200 m^2 and average depth ≈4.5 m. The construction area was divided into separate stabilisation basins in which the stabilisation work was done in phases. First the old blasted rock aggregate was removed from the stabilisation basin area and transported for further processing and utilisation.

After the aggregate had been removed the basin was filled with abandoned clay. The basins were already naturally partially filled with water, and the density of the abandoned clay was adjusted by mixing a wanted amount of the abandoned clay with the water uniformly so that about 1500 kg/m^3 density was achieved. The mixing was done with the mass stabilisation machine. After that the binder was mixed with the clay using the mass stabilisation machine.

After the stabilisation a non-woven geotextile was spread over the stabilised mass and compression embankment was spread over the geotextile. The compression embankment also worked as a stabilisation platform for the stabilisation machine. The mixing of the binder, geotextile and the compression embankment can be seen in the Figure 9.

A test stabilisation was carried out before the actual construction. The test stabilisation basin was divided into four stabilisation areas which were stabilised by using different binder amounts (kg/m^3).

Following the stabilisation and one month of curing time the strength properties of the stabilised mass was tested. The soundings showed that the stabilisation had been successful and all of the sounding points reached the required shearing strength (about 50 kPa, compressive strength ≈ 100 kPa). In most of the sounding points the shearing strengths were even many times higher than 100 kPa.

The actual stabilisation was made on the basis of the results of the test stabilisation. The water content and the density of the samples were followed at every stabilisation basin. Samples were collected from the basins to determine the water content and the density of the sample on site. One of the samples was sent to the laboratory to assure that the results were similar in the laboratory and on site.

Soundings were performed also after the test stabilisation on the actual construction stabilisation. The results showed that the shearing strengths were mostly over 100 kPa which fulfilled the criteria of 50 kPa shearing strength.

Figure 9. Arcada II. In the front left of the figure the binder is mixed with the abandoned soil with mass stabilisation machine. On the back right the compression embankment is being spread. (Arcada II; 14.7.2011)

4 PILOT 2 – DOG PARK

4.1 Background information about Dog park

Dog Park is another pilot of the Absoils project, which will be built in Espoo, Perkkaa in 2012 (see the location at Figure 3). The area of the park is 3500 m^2. The ground in the area is soft clay with low load bearing capacity. The ground level varies from +0.5 to +1.0 and flood covers the area from time to time. The thickness of the clay is about 12–14 m and the area is classified as very difficult constructing area of deep soft soil. An example of the ground researches of the area are presented in Figure 10. The water content of the clay layer is 80-130 % and the shear strength is 8–11 kPa (unreduced).

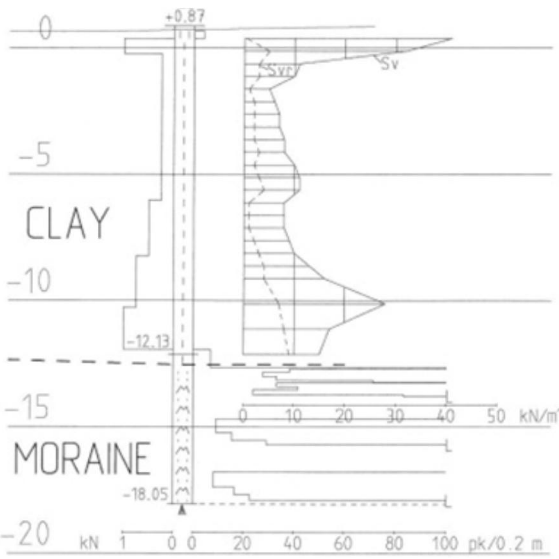

Figure 10. Dog park. Soundings – Swedish weight sounding test and vane test.

The ground level of the area is raised to prevent the flooding and the planned ground level is +2 – +2.5. The raising of the ground level will be done with abandoned soil which is stabilised together with the upper part of the original soil. The target is to reduce the occurrence of flooding to less than once in 20 years. The calculated consolidation settling of the embankment is about 200–300 mm during 30 a (without stabilisation the settling is ≈ 1 m). The area plan is presented in Figure 11.

The targeted shear strength after mass stabilisation is 30 kPa (28 d) and 40 kPa (90 d). The thickness of the stabilisation is planned to be about 3 m and the volume 13000 m^3. No wells for the rain water are built, but the drainage is done by surface inclination. The planned cross sectional cut is presented in the Figure 12.

For the area there is no other sensible method for the constructing of the dog park except for mass stabilisation method. No high load bearing is required from the area so the utilisation amount of binders will be small. The area of the dog park is owned by the ABSOILS steering group member - the city of Espoo.

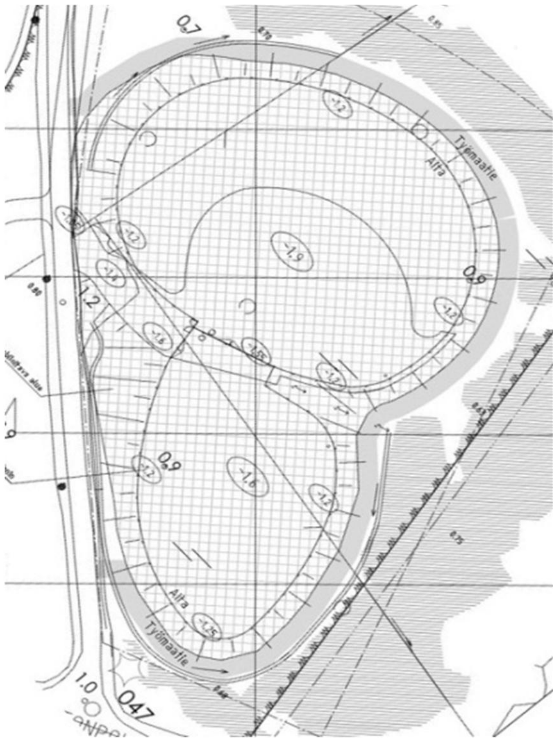

Figure 11. Area plan for Dog park. A ≈3500 m^2.

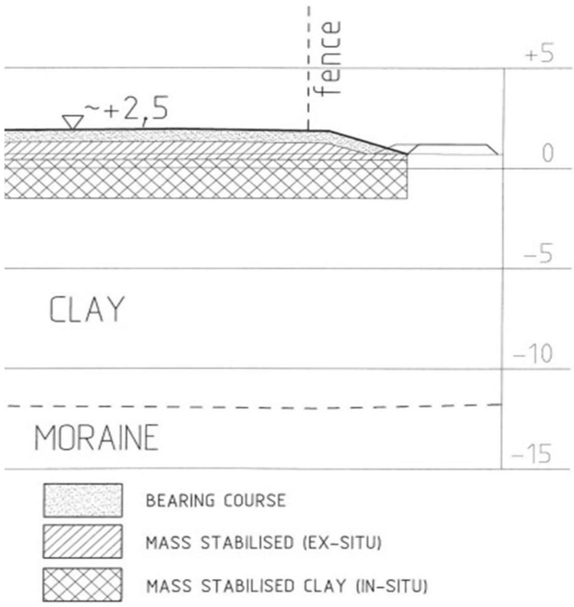

Figure 12. Dog park. Cross section.

4.2 Laboratory testing of Dog park

The stabilisation tests were done with the soft soil material from the park area. Both, commercial and alternative binder materials were tested. The alternative materials included fly ash (FA) from two different power plants (both wet and dry), gypsum (gyp.) and flue gas desulphurisation gypsum (FDG). The commercial binders tested were cement and lime-cement (KC).

The results of the stabilisation tests with cement and cement mixtures are shown in Figure 13 and Figure 14.

The results show that cement mixtures work similarly to when only cement is used but the mixtures bring a small benefit for the compressive strength. The two different fly ashes worked similarly when they were dry. The wet Inkoo fly ash did not improve the compressive strength with cement. The flue gas desulphurisation gypsum improved the 90 days compressive strength result slightly. The differences between the binder options could be clearer with longer curing time.

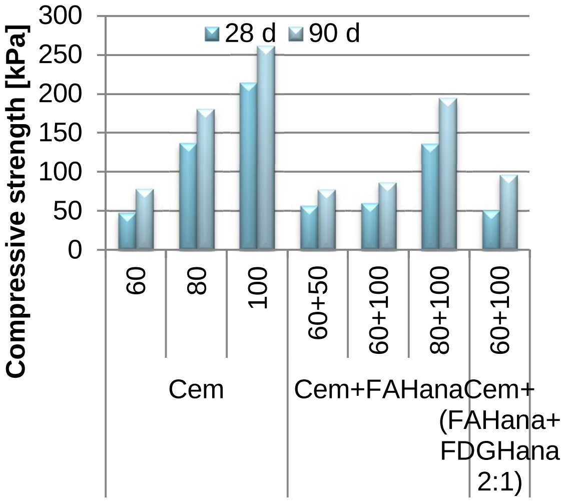

Figure 13. Compressive strengths with cement-fly ash (Hanasaari) - flue gas desulphurisation gypsum mixtures

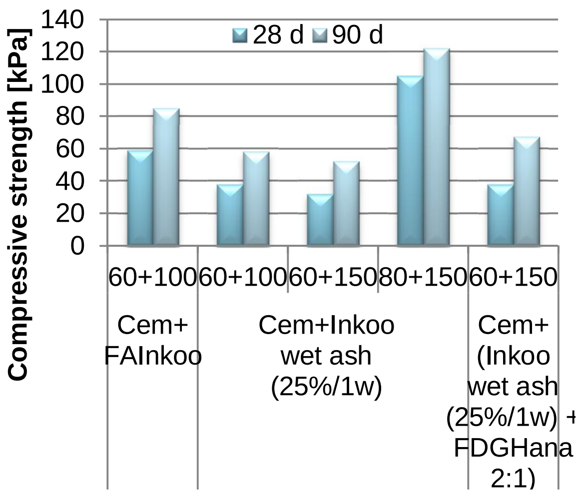

Figure 14. Compressive strengths with cement – fly ash (Inkoo)-flue gas desulphurisation gypsum mixtures. 25 % /1w means that the ash has been put in a water content of 25 % and held there over a week before using the ash as a binder.

The results of the stabilisation tests with lime-cement (KC) mixtures are presented in Figure 15.

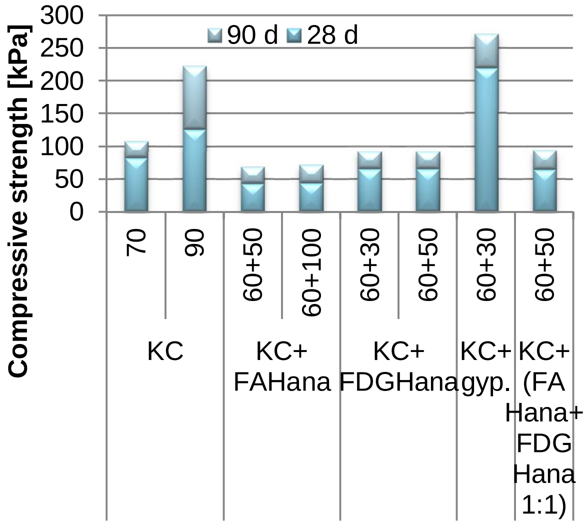

Figure 15. Compressive strengths with KC and KC mixtures.

The results show that by using gypsum-KC -mixture the amount of KC can be dropped at least 30 kg/m^3. The other binder mixture options were not as feasible. By dropping the amount of cement or KC savings can be made and also the carbon footprint of the project decreases.

The best binder option according to the stabilisation tests was KC-gypsum mixture. The construction process has not started yet and the binder agent used in the stabilisation will be decided later.

4.3 Construction process in Dog Park

The construction process has been designed so that the stabilisation work is done on site. Before the stabilisation work all vegetation including trees and their roots must be removed. The abandoned clays are transported to the stabilisation site where the materials are spread in the area surrounded with an embankment to prevent the escape of the clay material off from the stabilisation area. The stabilisation is planned to be performed with the mass stabilisation method.

The abandoned clay is from the site next to the Dog Park, from where the transportation distance is only 200–500 meters. If it wasn't possible to use the abandoned clays in the construction of Dog

Park, the transportation distance to the landfill would be 23 km. The abandoned clay is very troublesome and expensive material to dump to the landfill site.

The pilot is required to obtain the approval of the environmental authorities before the construction process can begin because industrial by-products are planned to be used in the stabilisation. The environmental authorities categorise the industrial by-products as waste. The construction work will begin as soon as the environmental permit is received and the weather is suitable for the mass stabilisation.

5 CONCLUSIONS

As a conclusion form these two pilots it can be said that abandoned clays are potential materials for construction use. The laboratory test results and the pilot in Arcada II show that the abandoned clays can be used in construction by modifying the material so that the strength and the modulus of the material are enhanced.

The laboratory test results show that the alternative binder materials such as fly ash and flue gas desulphurisation gypsum can used to replace cement in stabilisation, without reducing the compressive strength of the structure. These two sites show that different binder options should be carefully looked in to, as same binders work differently with different materials. For example flue gas desulphurisation gypsum enhanced compressive strength in Arcada II case but decreased it in Dog park case.

By using alternative binder materials, the cost of the binders can be reduced and also CO_2 emissions can be reduced. However, the environmental permit is required in case alternative binder materials are used because of the classification of such products as waste.

The laboratory tests are important part in the utilisation of the abandoned soils as the properties of the soils vary a lot and different binders work in different ways depending on the material properties. In the Arcada II case one material was disqualified from the stabilisation because the laboratory test results showed no increase in the compressive strength when the material was stabilised with 100 kg/m^3 of cement.

In case the utilisation of the industrial by-products is possible, then savings can most probably be made. The environmental permission processes need improving so that the slowness of the permission process does not become an obstacle in the utilisation of the by-products.

The sounding results from Arcada show that by mass stabilisation on site the targeted shearing strengths can be achieved and even exceeded.

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