LIFE09 ENV/FI/575 ABSOILS

FINAL REPORT / ANNEX 2

Final Report on Materials Action

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1. Introduction

This Final Material Report represents the results of five different pilot sites built in 2011-2014 within the framework of the ABSOILS project.

The first pilot site is Arcada 2 where a light weight structure was made by stabilising surplus soil material. The construction work on the site started in the beginning of 2011 and was finished in October 2012.

The second pilot site is in Jätkäsaari, in Helsinki, where dredged sediments were stabilised in 2011-2012 and the stabilised sediments were transported to a nearby park where they were utilised in a park structure. Some of the stabilised sediments were used in the cover structures of landfilling sites. Works in the Jätkäsaari continued in 2013, 2014 and 2015. By the end of 2014 and in 2015, two trial noise barriers were constructed at the site. After the trial period, the stabilised material will be used in the city of Helsinki for construction of noise barriers. For the needs of the Absoils project, piloting works in Jätkäsaari were divided into three phases. This division is reflected in project reporting.

The third pilot site described in this report is a Dog Park in Espoo. It was built in 2012. At the site, the ground level was raised with surplus soils and the new and the old soil material were mass stabilised. This report represents the results of the material tests conducted.

This report includes also preliminary material test results for a Länsisalmi site Vantaa which was originally planned to be carried out in the framework of the Absoils project. This did not take place due to the reasons not dependent on the project but the results add to the information on the stabilisation potential of soil materials in the Helsinki area.

The fifth pilot site covered in this report is a Honkasuo site in Helsinki, where a new residential area is under construction. The tests were carried out in 2014.

2. Methods

The material tests were performed according to the following methods.

Water content (SFS 179-2 – CEN ISO/TS 17892-1:fi) describes the ratio of water to the dry mass of the material. The water content is measured by drying the sample in an oven at 105 °C temperature until dry. The water content is calculated according to the formula

$$w = \frac{m_m - m_d}{m_d} * 100\%$$

where m_w is the wet mass of the sample and m_d is the dry mass of the sample.

Loss of Ignition (LoI) (SFS-EN 1997-2 5.6) describes the content of organic matter and crystal water in the material. In the determination of LoI a small amount of dry sample is kept at 800°C (dredging sediments at 550°C) for three hours. In the course of heating the organic matter is combusted and crystal water is evaporated. The loss of ignition is calculated from the loss of mass in relation to the dry mass of the sample according to the formula below.

$$LoI = \frac{m_d - m_i}{m_d} * 100\%$$

where m_d is the dry mass of the sample and m_i is the mass after ignition.

Usually LoI is determined as the average of two samples. Crystal water has to be reduced from samples with clay content equal to or more than 10% of its mass.

pH is determined by mixing dry soil with ion-exchange water in a ratio of 1:5 per mass. If the sample is studied wet in its natural composition, the water content has to be known and taken into consideration to ensure the correct ratio. The sample is mixed for five minutes and then let to settle for 2-4 hours. After settling the solution is mixed again and the pH is measured with a calibrated pH instrument.

Particle Size Distribution (SFS 179-2 – CEN ISO/TS 17892-4:fi) is determined by sieving and sedimentation tests. The proportion of particles smaller than 0.063 mm is determined with wet sieving, while sedimentation test reveals the more accurate distribution of grains smaller than 0,063 mm. The particle size distribution of 32–0.063 mm particles is determined by dry sieving.

Density control for samples is done by adding a determined amount of water to the sample which is then homogenised. The density of the sample is measured by filling a cylinder with known mass and volume with the sample and weighting the total system. The density of the sample is calculated by dividing the mass of the sample inside the cylinder with the volume of the cylinder.

Preparation of the aggregate specimens. The preparation of the specimens begins with calculation of the amounts of binders mixed with the aggregate (clay, dredged sediment ect.). The aggregate and the binders are mixed in laboratory mixer for 2 minutes. After mixing the mixture is compacted in to a cylinders having uniform diameter (42...50 mm) and the cylinders are put in to plastic bags to prevent the drying of the specimens. For the first two days the specimens are kept in room temperature after which the specimens are put in refrigerator (+8 ^{o}C) to stabilise. The specimens can also be thermally treated in which the specimens are stored in thermally insulated in +30^{o}C temperature. Usually the stabilisation time is 28...90 days for normally treated specimens and 3...14 days for thermally treated specimens, but the stabilisation method and time is determined separately for every material. The target of thermal treatment is to find out the potential maximum unconfined compressive strength of the material, but usually it is not recommended to use the values in designing the actual structures. Before testing the unconfined compressive strength the specimen is cut so that the height of the specimen is twice the diameter of the specimen.

Preparation of the peat specimens for the unconfined compressive strength test begins with mixing the sample. The amounts of the binders are calculated in relation to the density of the soil [kg/m^3]. The soil and the binders are mixed in a laboratory mixer for 2 minutes. After that the mixture is compacted in cylinders having uniform diameter of 68 mm and height of 195 mm. The specimens are put in to a loading bench where the cylinders are put under 18 kPa load (see Figure 1). The difference between the original height of the specimen and the final height after the stabilisation period is being recorded. The temperature on the load bench is about 18 °C for normal specimens and 30 °C for thermally treated specimens. The constant moisture content of the specimens is insured by having the bottom of the specimen cylinder under water. Usually the curing time is 28...90 days for normal specimens and 3...28 days for thermally treated specimens. With the thermal treatment the aim is to find out the potential maximum unconfined compressive strength of the material. However it is not recommended to use the values in the design of the actual structures.

Before testing the unconfined compressive strength the specimen is cut so that the height of the specimen is twice the diameter of the specimen.

Figure 1. Loading bench and peat specimen samples.

Unconfined Compressive Strength, UCS, (adjusted SFS 179-2 – CEN ISO/TS 17892-7:fi) is a standard test where a cylindrical test piece is loaded with a steady rate, until failure occurs (see Figure 2). The loading rate is 1 - 2 mm/min. If any noticeable failure does not occur, the maximum value of the compressive strength is taken when the deformation (change of height) is 15 %. Usually, the test will be made on test pieces after at least 28-30 days stabilisation.

Figure 2. Unconfined compressive test in progress. Ramboll Finland Oy.

Modified diffusion test (NVN 7347) is used to study the leaching of harmful substances from stabilised specimens. The result gives the cumulative amount of the harmful substances released from the top surface of the specimen (mg/m^2). In the diffusion test the test specimen is wrapped in a teflon tape all around except for the top surface, which is covered with glass pearls. The specimen is submerged in to water which has pH 4. In modified diffusion test the water is changed twice, first time 4 days and second time 14 days after the beginning of the of the test. The last water sample is taken 64 days after the beginning of the test. The pH and the electrical conductivity of the water samples are tested and also concentration of anions and metals are analysed from the water samples. The analysed substances are the same which are presented in the Finnish legislation about the use of fly ashes in earth construction (VNa 591/2006 and Vna 403/2009). The analysis methods of the water samples are based on the standards SFS-EN ISO 10304(1-2), ISO 17294-2, SFS-EN ISO 15587-2, SFS-EN ISO 15587-1.

The standard to be used in the modified diffusion test standard has changed (EA NEN 7375:2004) and since year 2013 the test has been performed like described in previous paragraph, but the water used in the test is ion exchanged water with the pH of 7.

The Proctor compaction test (SFS-EN 1997-2 5.10) is used to establish the maximum bulk density (dry) and the optimum water content of a material. In enhanced Proctor compaction test, the sample is compacted in five different layers into the mold of a known volume. Each layer is compacted 25 times with a Proctor hammer. The compacted sample is weighed and dried, which gives the water content at the time of compaction as well as the dry bulk density. Commonly four compactions at different water contents are required to ascertain the optimum value.

3. Materials

This chapter contains the presentation of the material test results carried out for the Absoils project. In all the material tests, the water content and loss of ignition were studied as they are the basic geotechnical characterisation tests for soil samples. In addition, pH and particle size distribution, etc. were studied for some samples.

3.1 Arcada materials

The results of Arcada 2 materials tests are presented in Table 1.

Table 1. Arcada 2 materials.

Sample	Water content w [%]	Loss of ignition LOI [%]	Particle size distribution	Density of the delivered sample in container / homogenized sample [kg/m^3]
Korpitie 1/1	31.4	2.8	-	1450 / 1880
Korpitie 1/2	32.6	2.8	-	1370 / -
Korpitie 1/3	33.1	4.4	-	1380 / -
Koivukylä	31.1	4.8	-	1500 / 1820
Korpitie	15.5	-	Cl	1200 / 1740
Piloting site/basin 3	67.1	-	clSi	1600 / -
Korpitie area 4/1 1,5 m	62.9	-	Cl	- / 1600
Korpitie area 4/2 1,5 m	32.9	-	Cl	- / 1820

The water content of the samples varied between 15.5...67 % and the LoI varied between 2.8...4.8 %. The targeted density of the homogenised sample after the addition of water was 1500 kg/m^3. The optimal water content of the sample was searched by the method explained in Chapter 2 (Proctor compaction test). The density control results are presented in Figure 3.

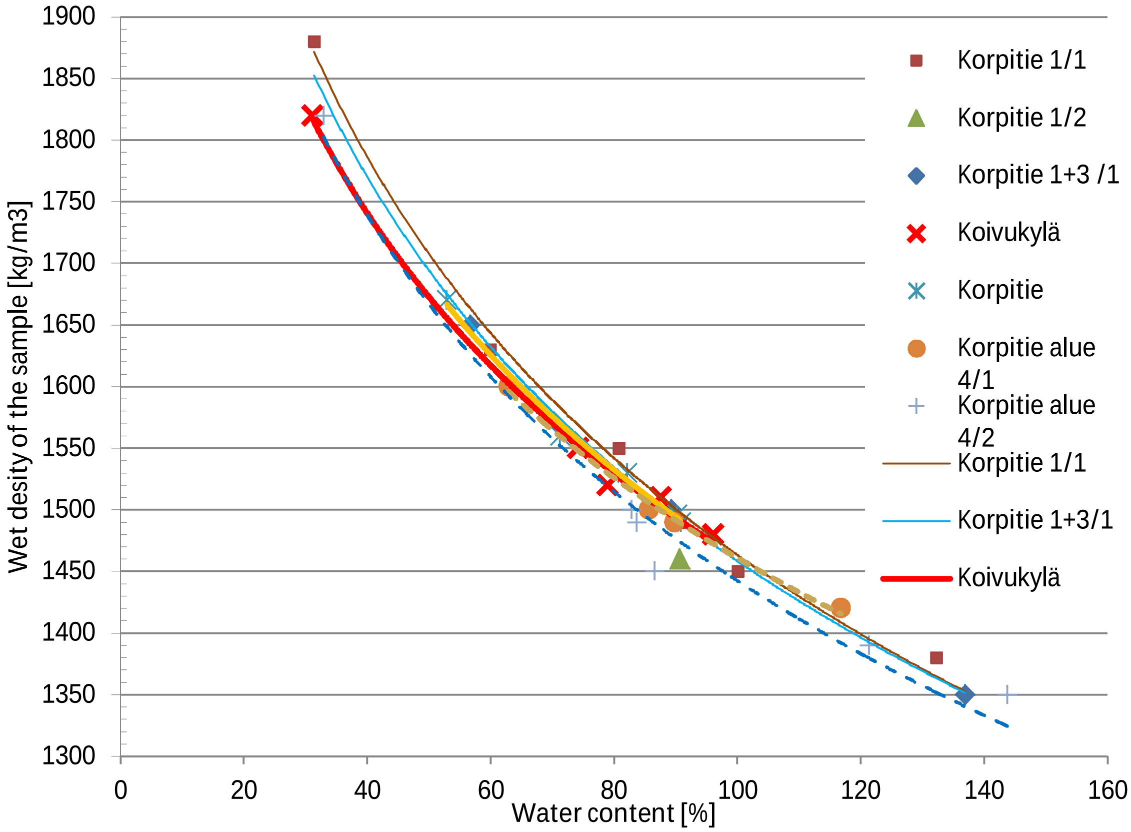

Figure 3. Results of the density control.

The results of the density control test showed that with all of the samples the optimal water content to achieve the 1500 kg/m^3 density was around 80-90 %.

3.2 Dog Park materials

The properties of the first samples of the Dog Park clay are presented in the table below.

Table 2. Dog Park first samples 2011.

Sample	Water content w [%]	Density ρ_m [kg/m^3]	Loss of ignition LoI [%]	Visual evaluation of soil class
0-1 m	88.8	1460	9.6	organic clay
1-2 m	111	1400	5.9	organic clay
2-3 m	103	1440	3.6	organic clay

The water content of the samples was around 100 % and the densities varied from 1400 to 1460 kg/m^3. The LoI value was higher in the ground surface but decreased towards the deeper layers.

The second set of samples was collected in the Dog Park about a year later (2012) after the first samples had been taken. The properties of the second set of samples are presented in the table below.

Table 3. Dog Park second samples 2012.

Sample	Water content w [%]	Density ρ_m [kg/m^3]	Loss of ignition LoI [%]	Visual evaluation of soil class
0-1 m	77.0	1540	4.2	organic clay
1-2 m	93.5	1480	3.6	organic clay
2-3 m	42.7	1800	1.7	clay
app. 3.8 m	30.3	1960	0.9	silt

3.3 Jätkäsaari materials

The properties of the Jätkäsaari sediments from the year 2011 are presented in the table below.

Table 4. Jätkäsaari materials/ 2011. The bolded samples are the ones used in the stabilisation tests.

Sample	Water content w [%]	Density ρ_m [kg/m^3]	Loss of ignition LoI [%]	pH
1 / 2-5 m	103	1450	3,8	8,1
1 / 5-8 m	89,1	1510	3,5	8,1
2 / 2.5-4.5 m	106	1440	3,8	8,0
2 / 7-9 m	82,7	1530	3,1	8,3
3 / 2-4 m	121	1410	3,9	8,0

3 / 5-7 m	73,0	1570	2,7	8,3
3 / 8-10 m	65,4	1610	2,6	8,3
4 / 1-2 m	119	1410	4,2	8,0
4 / 2.5-3.5 m	131	1370	4,5	8,0
5 / 2-3 m	111	1420	4,1	7,9
5 / 4.5-5.5 m	86,3	1510	3,6	8,2
5 / 7-8 m	111	1400	4,6	8,3

The water content of the samples varied between 65...131 % and was on average about 100 %. The density of the samples varied between 1370...1610 kg/m^3. The lowest LoI was 2,6 % (sample with the lowest water content) and the higher LoIs were 4,5...4,6 % (samples with the highest water content). The pH of the samples was around 8. The samples that are bolded were used in the stabilisation tests.

New samples from the Jätkäsaari stabilisation basins were collected before stabilisation took place in order to find out the suitable binder amount needed. The sampling points are presented in Figure 4.

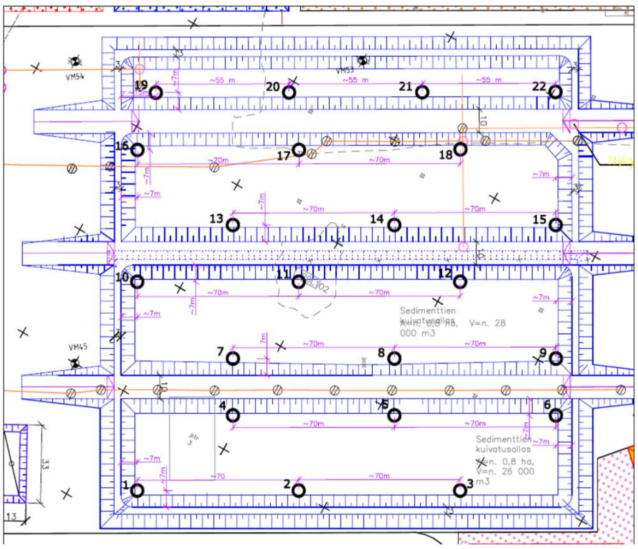

Figure 4. Jätkäsaari sampling points 2012 (black circles).

The properties of the new Jätkäsaari sediments 2012 are presented in

Table 5.

Table 5. Jätkäsaari materials 2012.

Sample	Depth [m]	Water content [%]	Loss of ignition LoI [%]
1	0,5	89,5	3,5

	1,5	84,2	3,4
	2,5	83,3	3,2
	3,5	77,2	3,2
2		81,1	3,4
3		71,2	3,2
4		79,7	2,9
5		69,2	3,2
6		54,1	2,9
7		80,4	3,1
8	0,5	79,8	3,0
	1,5	65,9	2,9
	2,5	70,9	2,9
	3,5	67,7	2,9
9		58,0	3,0
10	0,5	87,7	3,3
	1,5	86,7	3,5
	2,5	73,0	3,3
	3,5	82,2	3,5
11		65,9	3,4
12		73,4	3,2
13		66,1	3,4
14		91,2	3,7
15	0,5	96,2	4,1
	1,5	81,4	3,8
	2,5	82,7	3,4
	3,5	66,8	3,6
16	0,5	104	4,0
	1,5	99,1	3,7
	2,5	112	4,2
	3,5	108	3,9
17		91,3	3,9
18		85,4	3,8
19	0,5	28,8	1,6
	1,5	32,2	1,5
	2,5	55,7	3,1
20		26,1	1,3
21		159	8,7
22		111	4,9

The water contents of the samples varied between 26…159 %. The sampling points 16, 21 and 22 had over 100 % water contents and the sampling points 19 and 20 had really low water contents (26…56 %). The LoI level was around 3 % in most of the samples. The samples from the sampling points 19 and 20 had the lowest LoIs and the sampling point 21 had the highest LoI, which is consistent with the water contents. All the samples were clays except for the two last samples which included organic matter as well.

In the year 2013, a new basin was stabilised, thus new samples were collected. The sample points are shown in Figure 5.

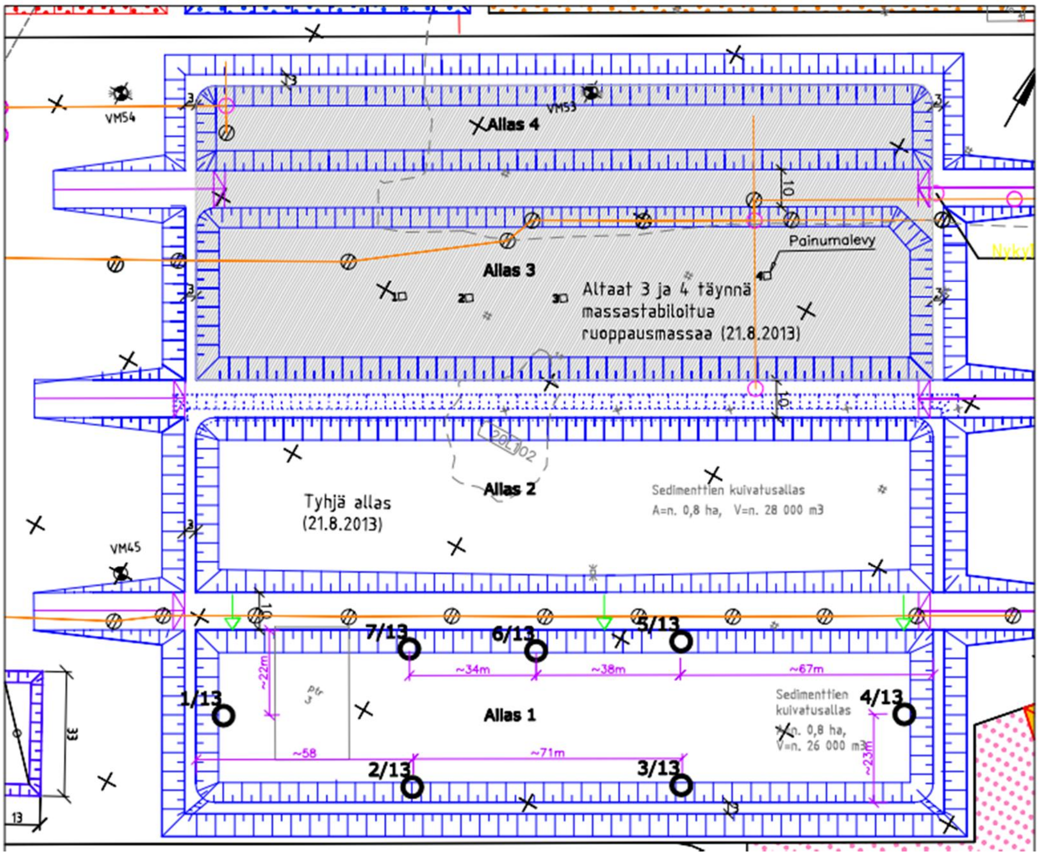

Figure 5. Sampling points of Jätkäsaari III in 2013.

The properties of the Jätkäsaari III sample point materials 2013 are presented in Table 6.

Table 6. Jätkäsaari III material properties in 2013.

Sample	Depth [m]	Water content [%]	Loss of ignition LOI [%]
1/13	0-1	85,7	(3.8)
	1-2	84,7	3,3
	2-3	69,6	(2.8)
2/13	0-1	70,3	
	1-2	65,8	2,7
	2-3	61,7	
3/13	0-1	71,2	
	1-2	78,3	3,2
	2-3	79,7	
4/13	0-1	66,6	
	1-2	67,2	2,6
	2-3	59,9	
5/13	0-1	91,3	(3.6)
	1-2	99,5	3,7
	2-3	108	(4.0)
6/13	0-1	65,3	

	1-2	69,0	2,7
7/13	0-1	64,0	
	1-2	56,5	2,4
	2-3	51,9	

The water contents of the samples were between 51.9...108 %. The sample point 7/13 had the lowest water content and the wettest point was 5/13. Loss of ignition was quite low in the studied samples.

3.4 Länsisalmi materials

The results of the Länsisalmi material tests are shown in Table 7.

Table 7. Sample material properties from Länsisalmi.

Sample	Water content w [%]		Loss of Ignition LoI [%]	
	Sample 1	Sample 2	Sample 1	Sample 2
P8, 2.5-3.5 m / 1st batch	47,4 [1]	56,2 [1]	2,9	4,2
P8, 2.5-3.5 m / 2nd batch	44,5 [2]	61,5	2,8	3,7
P8, 5.5-6.5 m / 1st batch	49	62,7 [3]	3,2	3,8
P8, 5.5-6.5 m / 2nd batch	62,4 [3]		3,3	
P18, 4-5 m / 1st batch	75,8 [4]		-	

The samples used in the stabilisation studies are marked in the table with numbers. The number 1 (P8 2.5-3.5m / 1st batch) samples were mixed together. The number 3 (P8 5.5-6.5m) 1st batch sample was mixed with 2nd batch. The samples 2 and 4 were used alone in the stabilisation tests. All of the materials were silt/clay with water content between 44 and 76 % and loss of ignition between 2.8 and 4.2 %. The number 1 samples are named in the results as P8 / "top layer" (mixture of Cl+Si), the number 2 samples are named as "coarse top layer", the number 3 samples are named as P8 / 5.5-6.5 m and the number 4 samples as P18 / 4-5 m.

3.5 Honkasuo materials

The characterisation results of Honkasuo materials are shown in Table 8.

Table 8. Characterisation of Honkasuo materials.

Sample point	Depth [m]	Water content w [%]	Loss of ignition LOI [%]	Particle size distribution	pH
PL 127	0,5-1,5	1399	95,3	medium decomposed peat H5	3,7
	1,5-2,5	1004	86,2	decomposed peat H8	4,5
	4,0-5,0	96,4	6,1	Cl	

	6,0-7,0	94,0	3,9	Cl	
PL 128	0,5-1,5	1004	97,3	medium decomposed peat H5	3,3
	3,0-4,0	134	9,4	Cl	
	4,0-5,0	109	5,9	ljSa	
	5,0-6,0	91,9	4,0	Cl	
PL 129	0,5-1,5	194	92,2	dry medium decomposed peat	3,3
	1,5-2,5	187	88,7	dry medium decomposed peat	3,1
	4,0-5,0	18,7	0,7	SiMr	
Savi 2		85,5	3,8	Cl	

4. Stabilisation results

The binders used in the stabilisation tests of the samples are presented in Table 9.

Table 9. Binders used in the stabilisation tests.

Abbreviation	Binder type	Producer
Cem	Portland cement (CEM II/A-M(S-LL) 42,5 N)	Finnsement Oy
CemPlus	Portland cement (CEM II/B-M(S-LL) 42,5N)	Finnsement Oy
SRSe	Sulphate resistant cement	Finnsementti
CaO	Lime	Nordkalk Oyj
KC / KC 3:7	Mixture of CaO and Portland cement, ratio 3:7	
GTC	Mixture of gypsum, hydrated lime and Portland cement	Nordkalk Oyj
FA	Dry fly ash from Inkoo Power Plant	Fortum Power and Heat
FAHana	Dry fly ash from Hanasaari Power plant	Helsingin Energia
Inkoo wet ash (25%/1w)	Wet fly ash (moisture one week before use to 25 % water content) from Inkoo Power Plant	Fortum Power and Heat
PKT/OSA8	Oil shale ash	Eesti Energy
gyp.	Gypsum from the production of phosphoric acid	Yara Suomi Oy

4.1 Arcada results

2011

The stabilisation potential of the Arcada materials was studied first with cement. Only cement was used as a binder in this case due to the tight schedule of the work. The effect of the wet density to the compressive strength was studied with the Korpitie samples 1+3 mixed in proportion of 1:1 and with Cem 100 kg/m^3 of binder. The results can be seen in Figure 26.

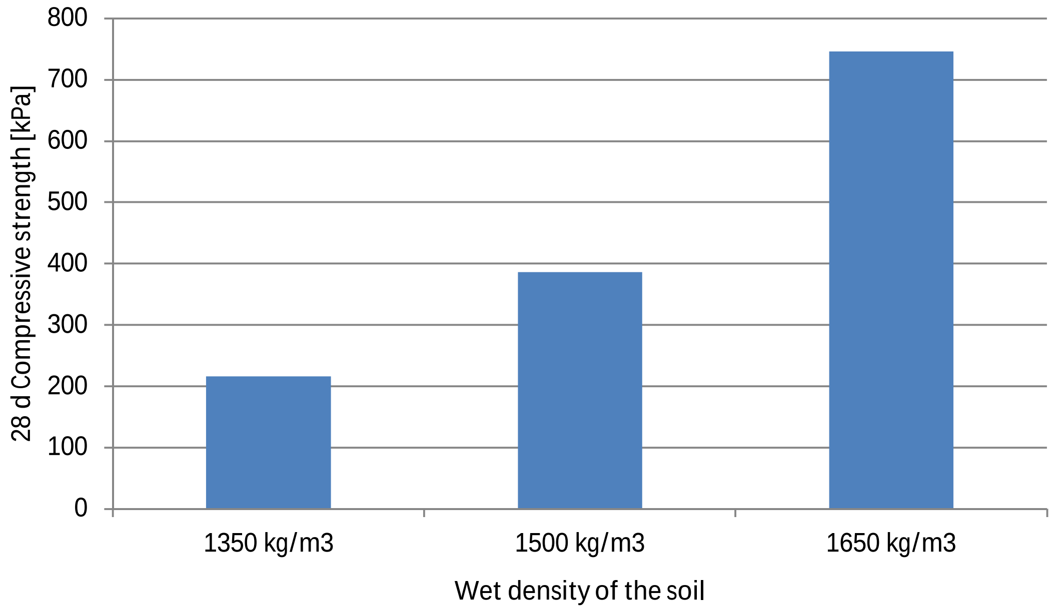

Figure 6. The effect of the wet density to the compressive strength with Cem 100 kg/m^3 used as a binder.

According to the results presented in Figure 6, the compressive strength is higher with higher wet densities. This is logical as the water content decreases when the density of the soil increases.

For the stabilisation tests of different kinds of soils, the density of 1500 kg/m^3 was chosen for the stabilisation test, except for the piloting site sample which was mixed in the piloting site with the water and delivered to the laboratory in that density. The density of the piloting site sample was 1600 kg/m^3. The results of the Arcada 2 stabilisation tests are presented in

Table 10.

Table 10. The results of stabilisation test with Arcada 2 materials.

Sample	Used binder	Binder amount [kg/m³]	Compressive strength [kPa]	
			7 d	28 d
Koivukylä	Cem	100	< 10 [1)]	< 10 [1)]
Korpitie	Cem	100	101	127
Piloting site/basin 3	Cem	100	322	428
Korpitie area 4/1 1,5m	Cem	100	583	747
Korpitie area 4/2 1,5m	Cem	100	502	662

[1)] No strength development

The compressive strength of different samples varied a lot. The first sample did not stabilise at all and was not used in the stabilisation and yet some samples had very high strength results.

The stabilisation tests were performed also using fly ash and sulphur removal products with the Korpitie sample mixture used in the first studies. The results of the testing are shown in Figure 7.

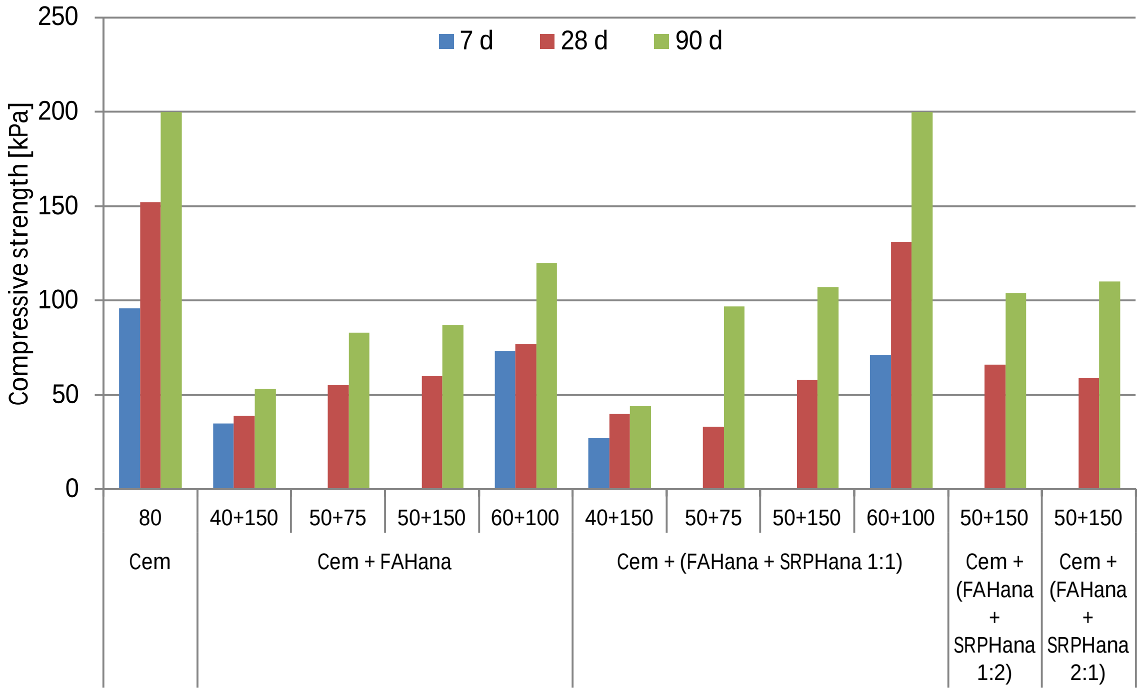

Figure 7. Arcada stabilisation test results when by-products were used as binders.

The figure shows that good results were achieved with by-products and that it is beneficial to use sulphur removal product in the stabilisation. The deSOx agent improved especially the long term strength development. No differences were noticed when the proportion of fly ash and sulphur removal product was altered.

4.2 Dog Park test results

2011

The targeted compressive strength for the Dog Park stabilisation was around 60-80 kPa. The Dog Park stabilisation tests were carried out first with a mixture of samples from the layers of 0-2 m. Only a few binder mixture samples were made with the separate layer samples of 0-1 m, 1-2 m and 2-3 m. The reason for the small scale testing was that during that time there was no information on the quality of the additional soil which was later on brought to the site for filling. The separate layer stabilisation tests were carried out in order to find out if the layers had any differences in the strength development properties. The results of the stabilisation test of the mixture sample are presented in Figure 8.

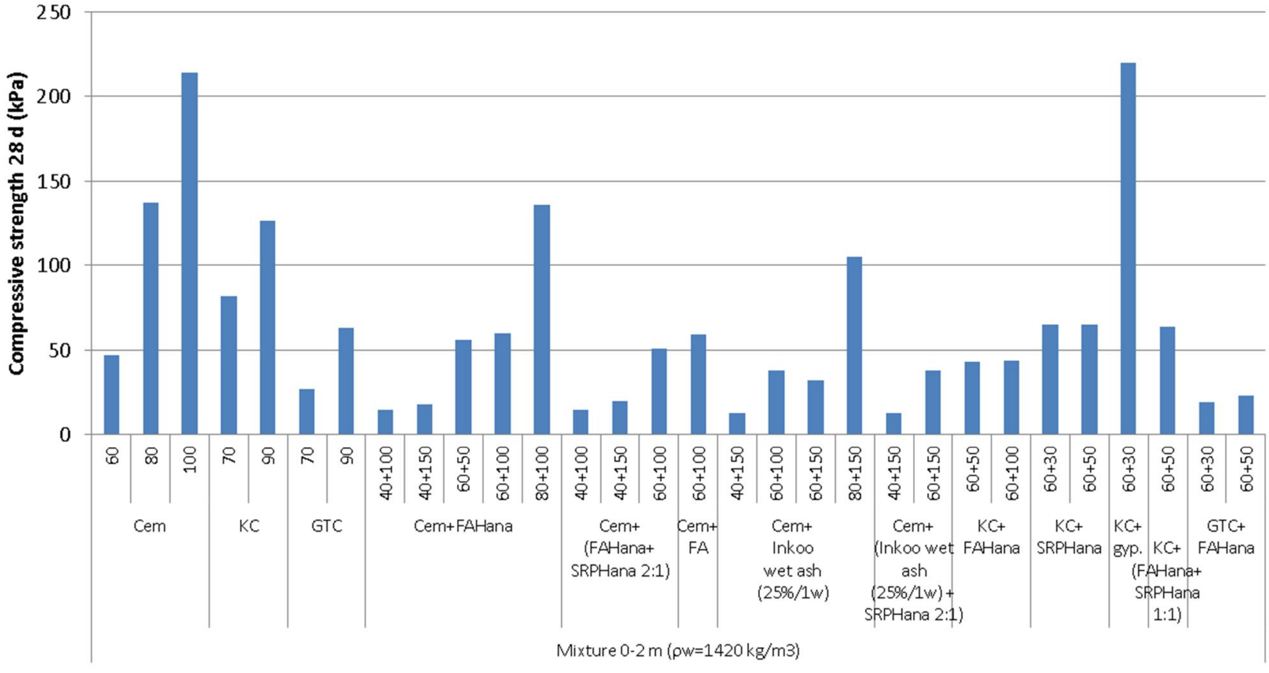

Figure 8. Stabilisation test results of sample mixture from the depth of 0 m to 2 m.

The stabilisation test results showed that:

- On the basis of Figure 8, the targeted strength can be achieved with the tested binders.
- The amount of cement needed for the stabilisation would be about 70...80 kg/m^3. With KC the required binder amount is 70 kg/m^3.

- Fly ash increased the compressive strength with cement but the amount of cement must be over 60 kg/m^3.

- The mixture of FA and SRP gave similar compressive strengths as Cem+FAHana. Both of the fly ashes worked similarly. The utilisation of wet ash and the mixture of wet ash and SRP decreased the compressive strengths.

- Fly ash mixed with KC did not increase the compressive strength but the use of SRP was beneficial. The utilisation of gypsum with KC gave good results and even a smaller amount of KC could improve the results if used with gypsum. This would be beneficial as the total amount of binder could have been decreased bringing financial benefit for the stabilisation process.

- The mixture of KC+FAHana+SRPHana gave poor compressive strength results compared to the total amount of the binders. Also GTC gave poor results.

These results gave some ideas about which mixtures worked best for the stabilisation purposes.

Figure 9 shows the results of all of the layers separately in order to find out the common differences between the layers according to the strength development and the required binder amount.

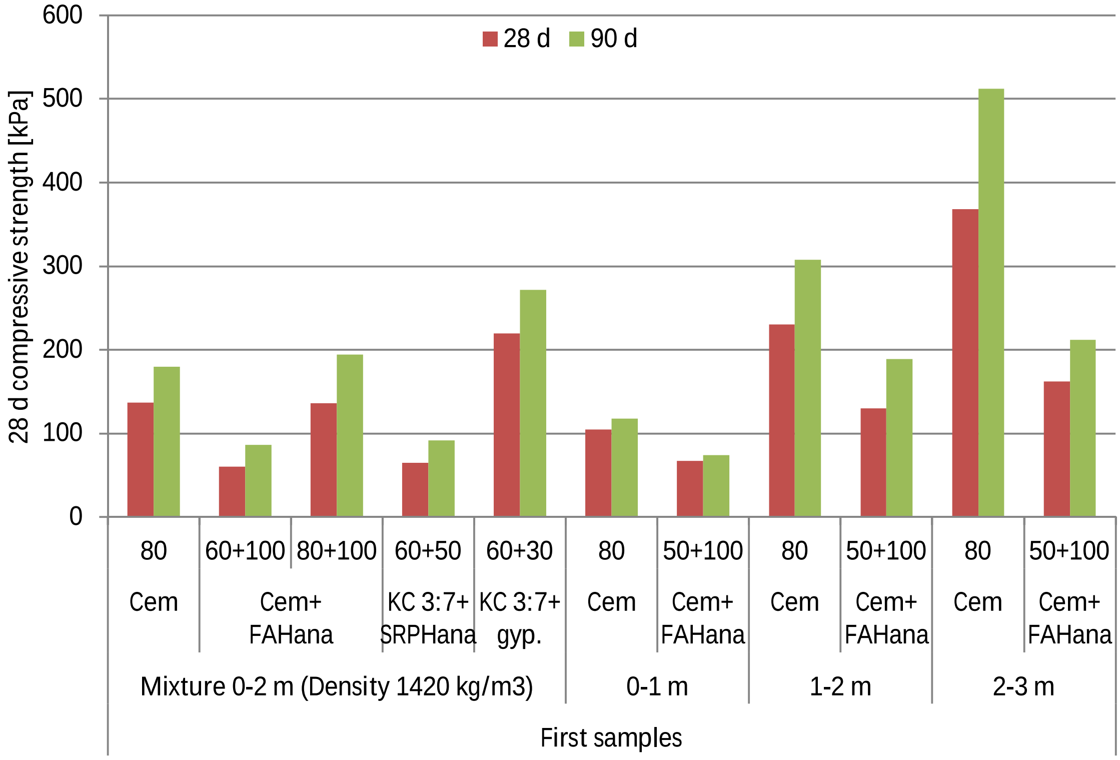

Figure 9. Stabilisation test results of different soil layers.

The results in Figure 9 show that the top layer of the soil had lower compressive strengths than the lower layers. The top layers had also higher LoI which might have affected the compressive strength results. The layer 2-3 m had the best compressive strengths and the lowest LoI, which means that a smaller amount of binders is needed compared to the upper layers. Gypsum is beneficial when it is used in small amounts.

2012

Further testing was performed with the second set of samples to find out if the results would be similar in the whole area and also to make final decisions about the binder amounts used in the stabilisation process. The results for the second set of samples are presented in Figure 10.

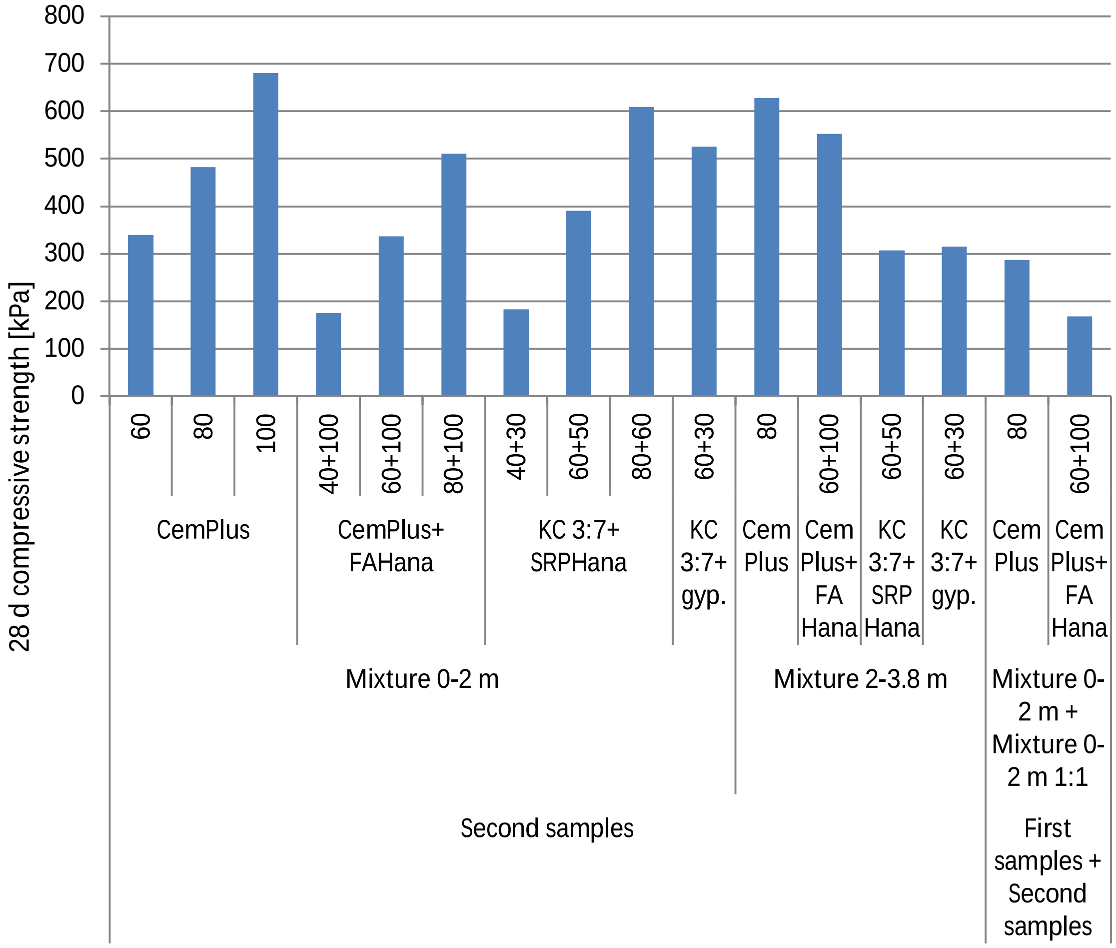

Figure 10. The compressive strength results with second samples.

The results showed that a lot better results were achieved with the second set of samples than with the first set of samples. With the lower layers, the differences were not as dramatic as with the upper layer (0-2 m) but still the compressive strengths were 1.5 times higher than with the first sample. The mixture of the first and the second samples showed that the compressive strength is about the same as the average of the compressive strengths of the two separate samples. The second studies were done with a new CemPlus which might have also had some effect on the results but also the lower water contents and LoI values might have played a key role in the bigger compressive strengths.

4.3 Jätkäsaari test results

2011

The Jätkäsaari stabilisation tests were carried out with five different sediment samples. The results of the stabilisation tests are presented in the two figures below.

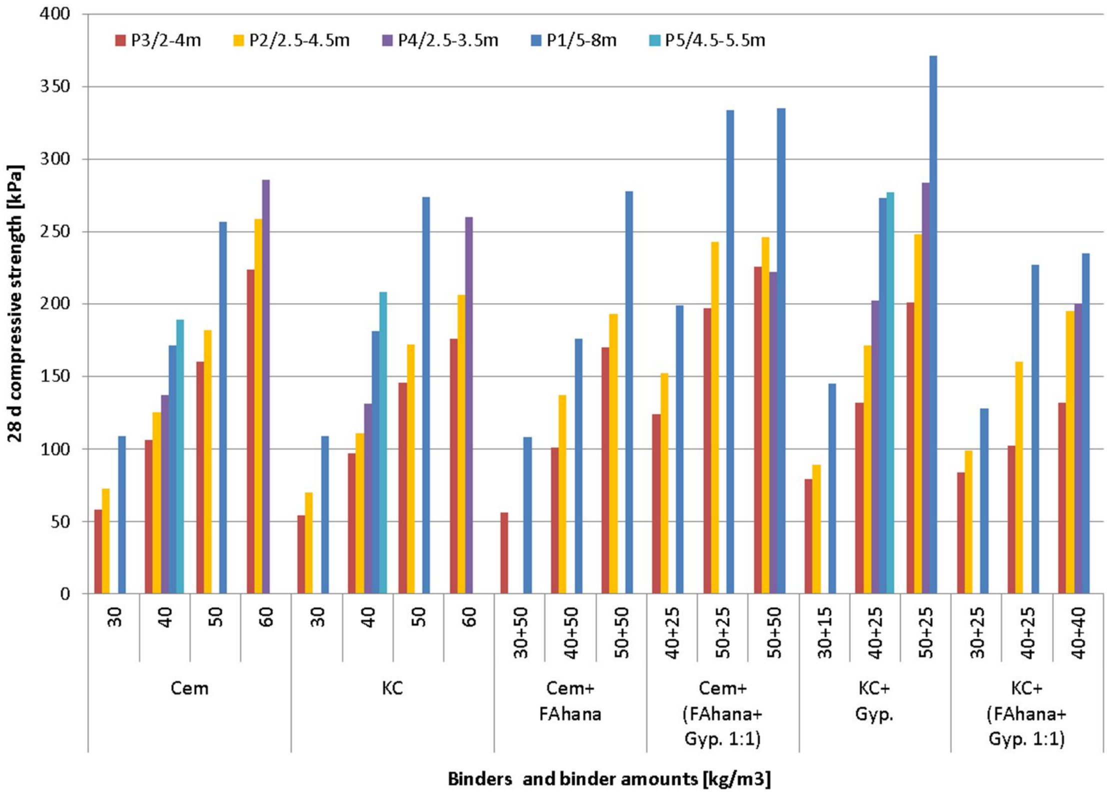

Figure 11 shows the stabilisation test results after 28 days of stabilisation.

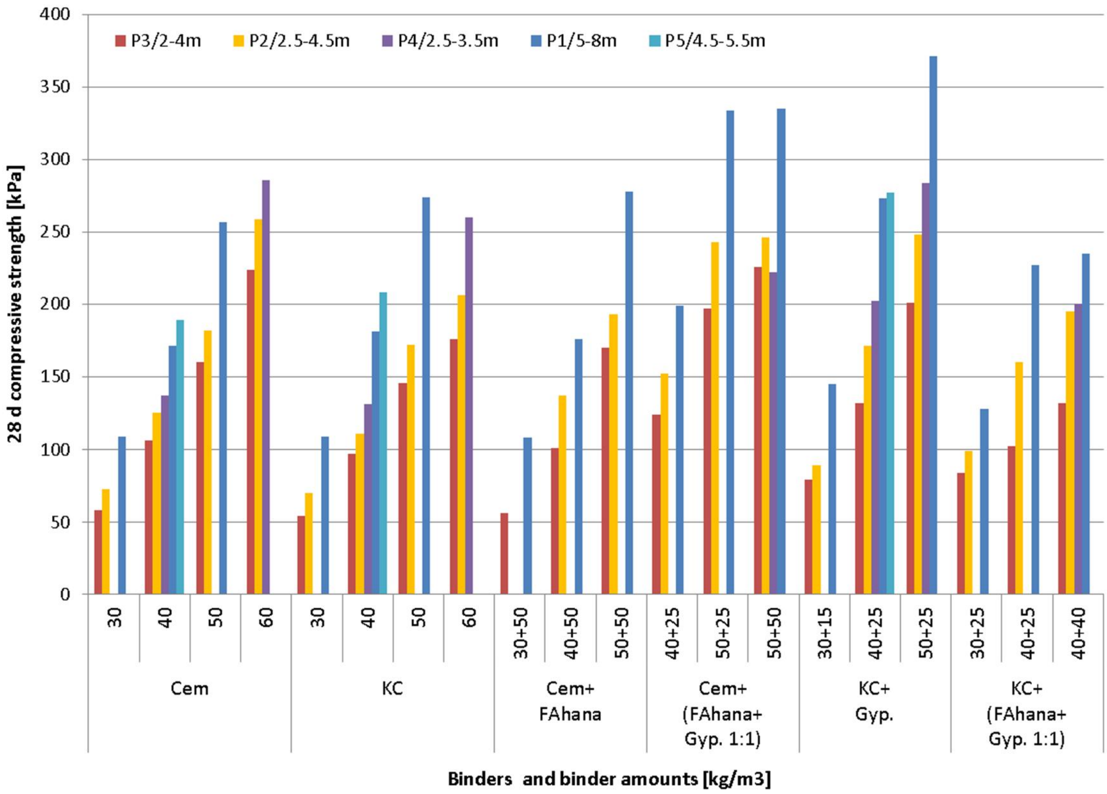

Figure 11. Jätkäsaari stabilisation test results after 28 days of stabilisation, 2011.

The results in Figure 11 show that the utilisation of gypsum together with cement and fly ash or with KC was beneficial to the strength development. The results show also that the wetter sample had lower compressive strengths than the drier samples.

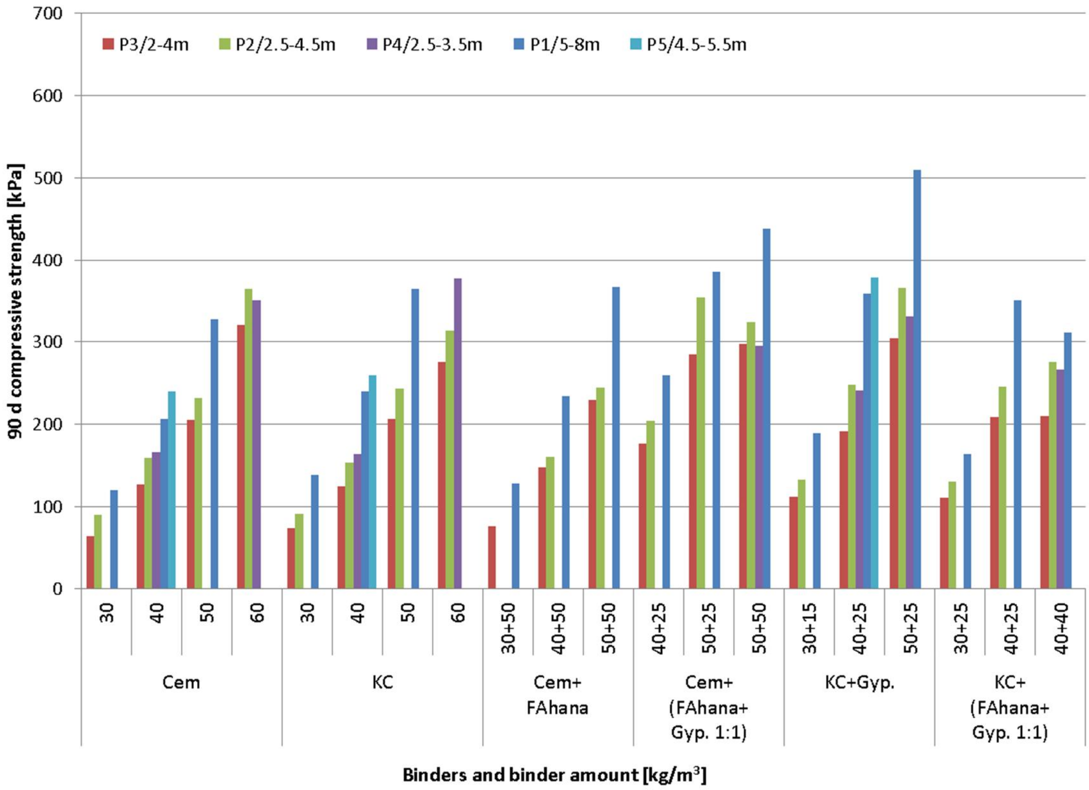

Figure 12 shows the test results after 90 days of stabilisation.

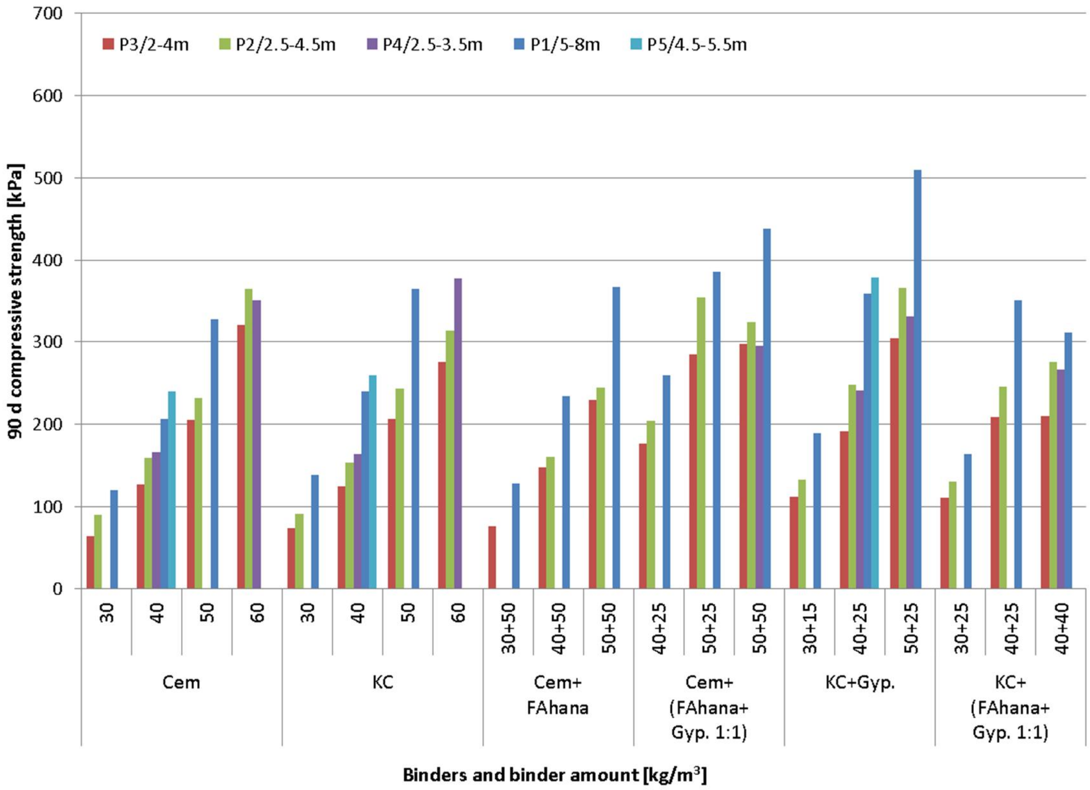

Figure 12. Jätkäsaari stabilisation test results after 90 days of stabilisation, 2011.

The results in

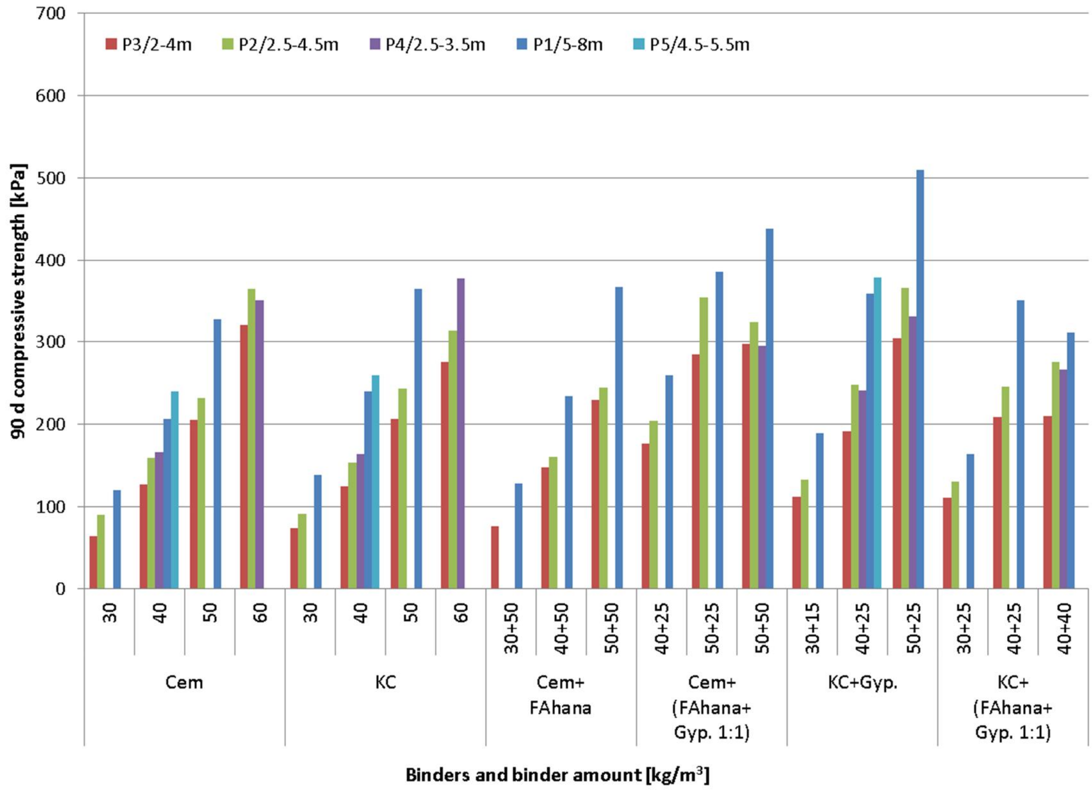

Figure 122 show that significant strength development occurred after 28 days of stabilisation. The best binder options according to these results were the mixtures of Cem+FAHana+Gyp and KC+Gyp. which gave the best compressive strengths with the relative low binder amounts.

2012

The stabilisation tests were repeated for the new samples. The stabilisation tests were performed only with Portland cement (CemPlus) and for all the sample points. The points with separate samples from different layers were homogenised so that the different layers were mixed together. The curing time of the samples was 28 days. The results are presented in Figure 13 and 14.

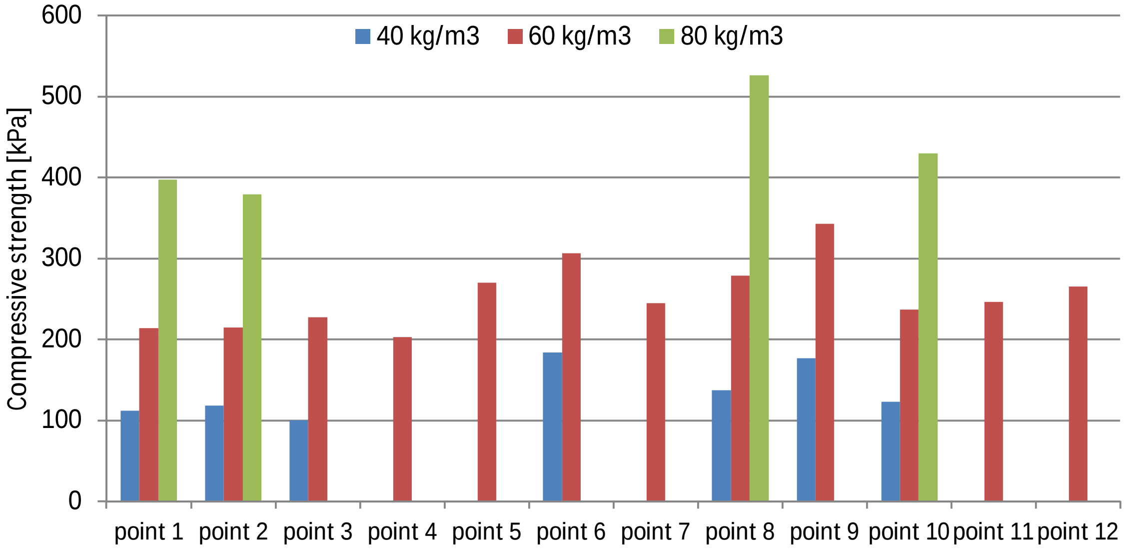

Figure 13. The stabilisation test results of Jätkäsaari 2012 samples 1–12.

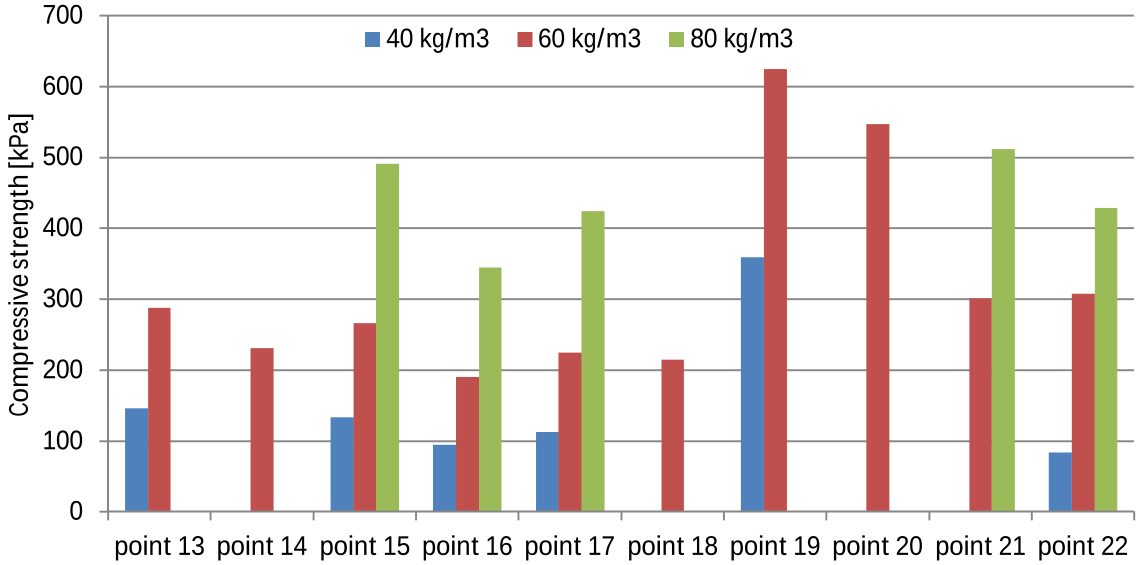

Figure 14. The stabilisation test results of Jätkäsaari 2012 samples 13–22.

The results showed that all the samples had good strength development properties, even the samples with the high LoI content. The targeted compressive strength level was about 150 kPa and the needed binder amount to achieve the target strength was about 40–50 kg/m^3.

2013-2014

In stage 3 of the Jätkäsaari pilot, stabilisation tests were carried out similarly as in the previous years. The tests were performed in two stages, first an average quality testing with a wide range of binders and preliminary sensitivity control on water content (with two binder options). In the second stage, the aggregate quality variation impact on the curing was tested with three separate aggregate material samples and by using two binder recipes.

At the first stage the binders were tested. The mass stabilised aggregate material was a mixture of 9 different samples. The samples contained all three depth samples (0-1 m, 1-2 m and 2-3 m) from the sampling points 1/13, 4/13 and 5/13. The water content of the aggregate material was adjusted with tap water to the level of 95 %. The used binders were cement (Cem), lime (CaO), fly ash (FAHana or FASalmi) and sulphur removal product (SRPHana new) and oil shale ash (OSA8). The target strength was 140 kPa. The maximum binder amount used was 200 kg/m^3. With every mixture 2 specimens were made, of which the compressive strength was tested after 28 days from the other specimen and on a basis of the first result and extra consideration, some specimens were also tested after 9 weeks. The results from the binder testing stage is divided into two Figures 13a and 13b due to a large data amount.

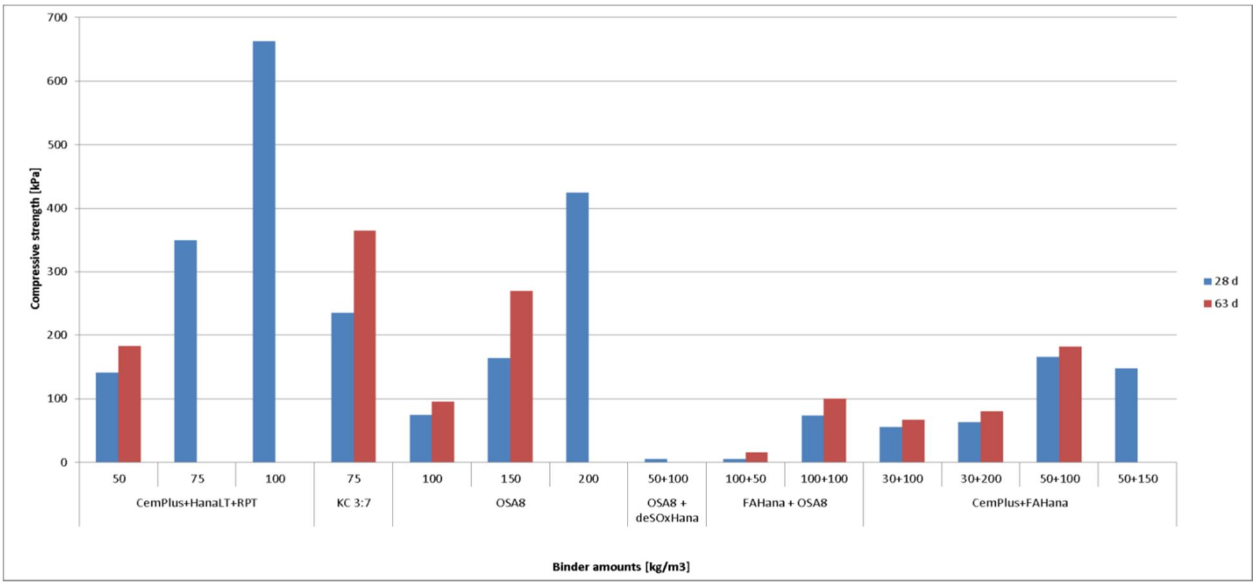

Figure 13a. The results from binder testing stage of Jätkäsaari 3.

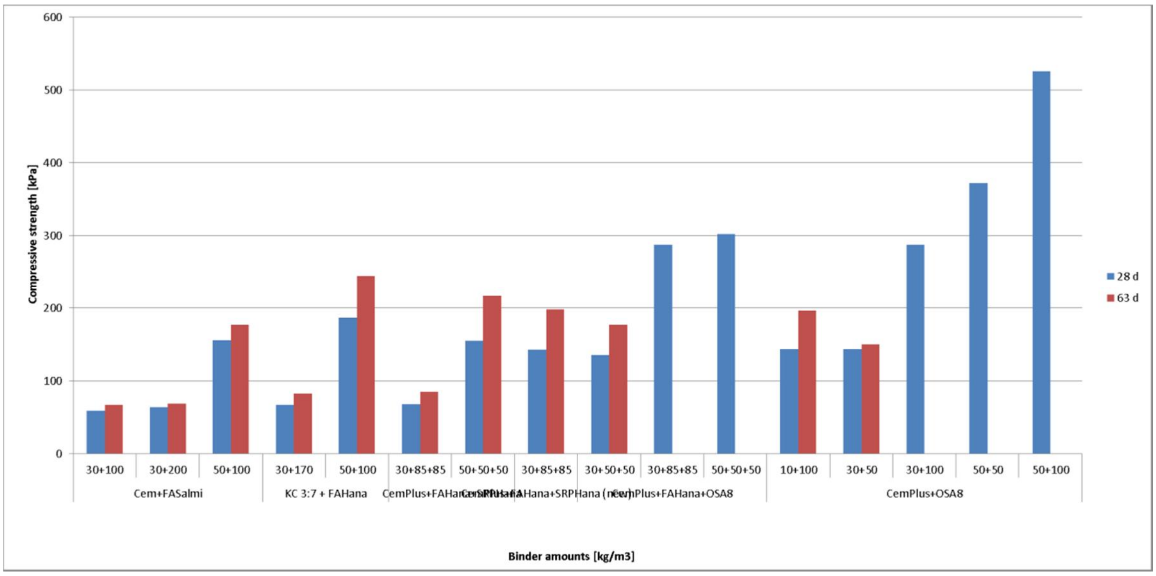

Figure 13b. The results from binder testing stage of Jätkäsaari 3.

When the water content sensitivity analysis was tested, the two most potential binder types were chosen for the test (CemPlus + FA and CemPlus). The water content was adjusted to the level -15...+30 % of what was used in the previous stage. When fly ash-cement-mixture was used, also comparison between unsalted water and salt water was studied. Results are shown in Figures 14 and 15.

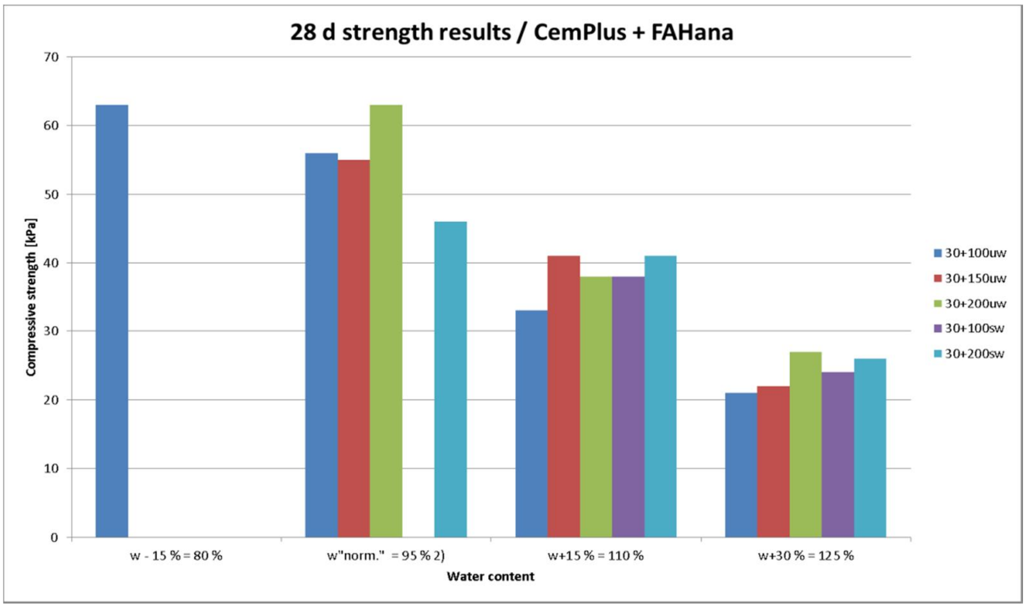

Figure 14. 28 days compressive strength results, binder CemPlus + FAHana. Abbreviation uw = unsalted water, sw = sea water.

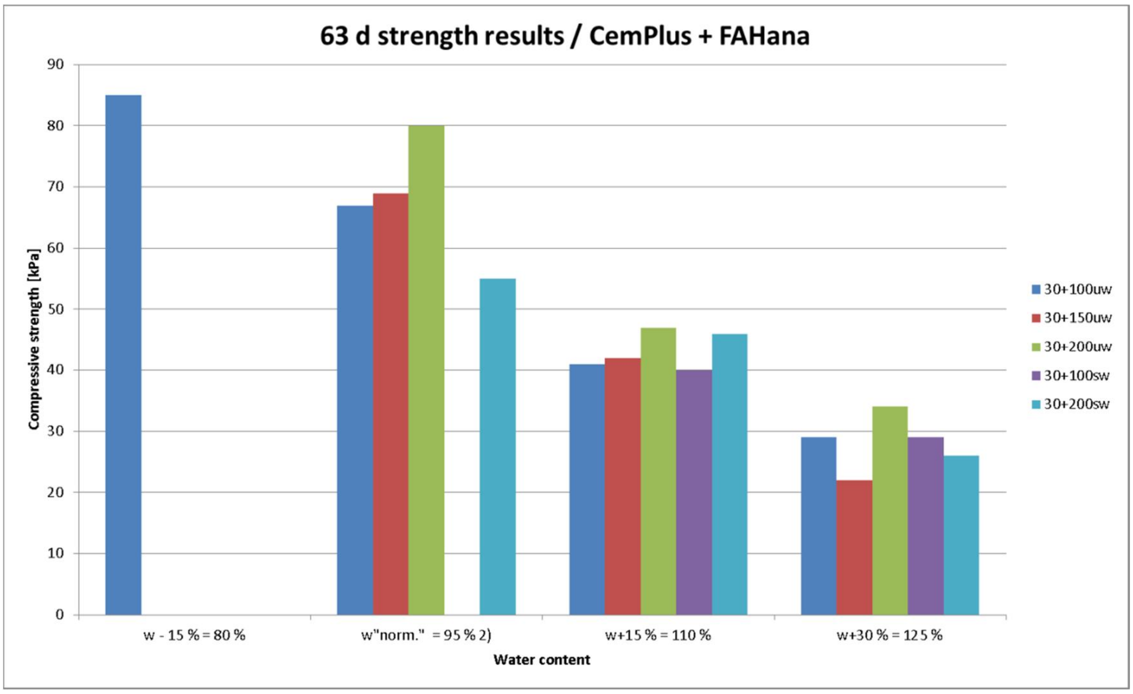

Figure 15. 63 days compressive strength results, binder CemPlus + FAHana. Abbreviation uw = unsalted water, sw = sea water.

On the basis of the previous stages (binder optimization and water content adjustment) the curing level was checked by using three different aggregate samples. The purpose was to get an overall view of the effect of quality on the stabilization result. Used binders were cement (CemPlus), fly ash (FAHana) and sulphur removal product (SRPHana new). The results are shown in Figure 16.

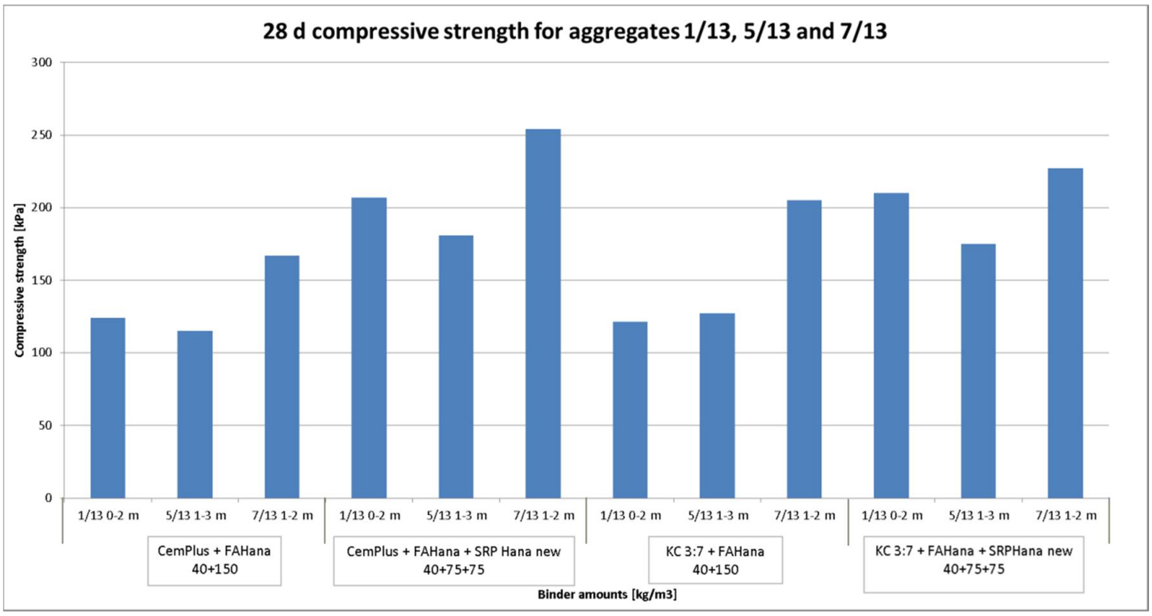

Figure 16. 28 d compressive strength results from three different depths.

The strength result was highest in sample point 7/13 (1-2 m) with every binder option. The highest strengthening result was achieved with the mixture of CemPlus + FAHana + SRPHana new 40+75+75 kg/m^3 (in sample point 7/3). The lowest strengthening result was 115 kPa with the mixture of CemPlus + FAHana 40+150 kg/m^3 (in sample point 5/13).

4.4 Länsisalmi results

2011

The stabilisation tests were carried out on four different samples and 6 different binder materials were used in different proportions. The results of the stabilisation test are shown in Figure 17 below.

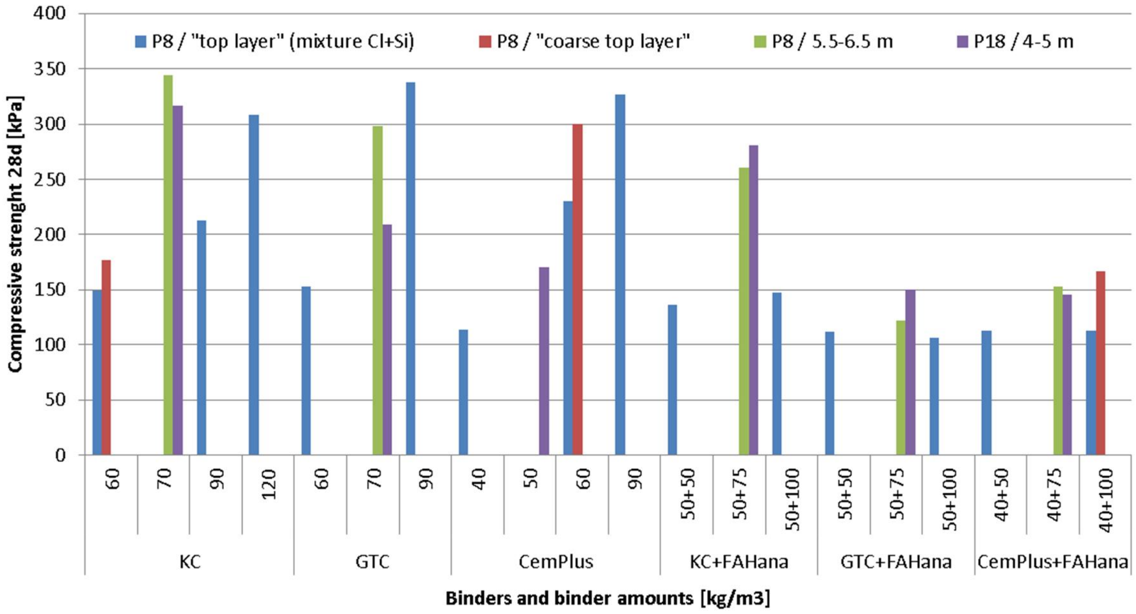

Figure 15. Stabilisation test results of Länsisalmi samples.

The results show that the samples P8/5.5-6.5 and P18 /4-5m achieved better compressive strength then the two other samples. The results show that the utilisation of fly ash together with a commercial binder allow for the decrease of the amount of the commercial binder in binder mixtures, which results in lower costs of the stabilisation process. The amount of the commercial binder in the stabilised samples is small but in spite of this, good enough compressive strength can be achieved. Very high compressive strengths can be achieved with bigger amounts of commercial binders.

4.5 Honkasuo test results

At Honkasuo mass stabilisation site, the lower part of the stabilisation reaches to the clay layer underneath. Honkasuo stabilisation tests were carried out in 2014, in two stages.

The index properties of the peats and muddy ground from the lower layer were examined by determining the water content, pH and loss of ignition. Sulphide and chloride content was tested for the peats.

Stage I results

In the first stage of the mass stabilisation tests, the reference testing was carried out for one examination point (Pt127) by using cement and a fly ash-cement-mixture (same amount of binder). This way the difference compared to curing of the muddy layer was examined.

The strengthening results of the first stage testing round are divided into two due to the large amount of data. The results are presented in Figures 16 and 17.

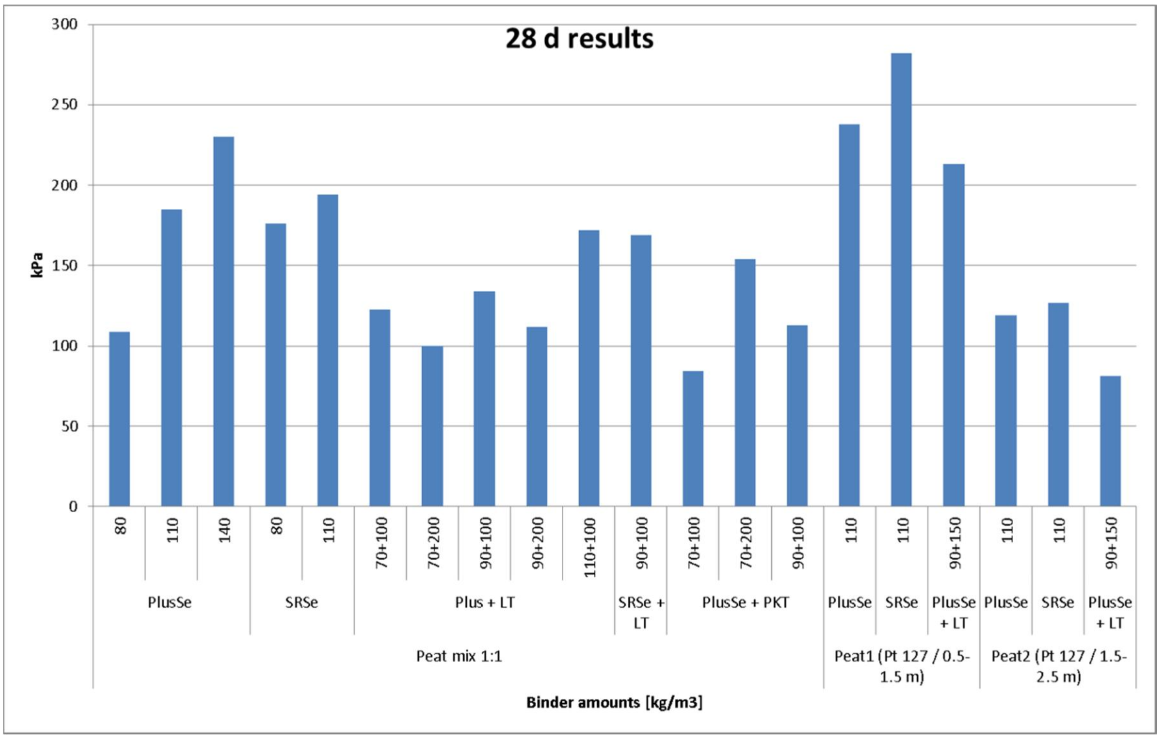

Figure 16. 28 d stabilisation test results of Honkasuo samples.

The peat mix represents the average strengthening of a peat layer, as the used aggregate is peat mix in proportion of 1:1. The reference testing was made with samples Peat 1 and Peat 2 to demonstrate how the peat stabilises in these points. The results show that the sample Peat 2 has lower strengthening properties with all the binders tested. The best strengthening result in peat mix 1:1 was achieved with cement 140 kg/m^3. When cement was partly replaced with fly ash 110+100 kg/m^3, the strengthening result was 172 kPa.

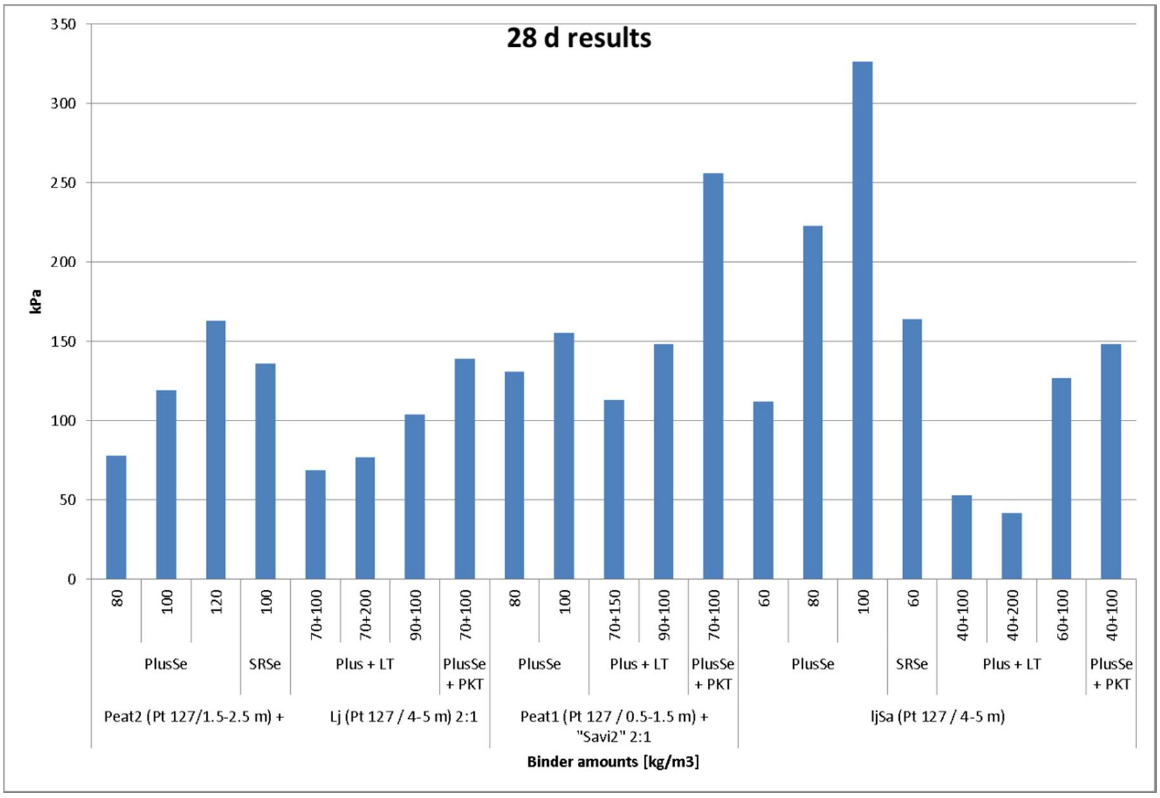

Figure 17. 28 d stabilisation test results of Honkasuo samples.

The strengthening results of the lower muddy layer and lower peat sample-mixture are presented in Figure 17. The mixtures were made in peat:clay proportion of 2:1. Also the lower part of mass stabilisation was tested. The results show that it is possible to replace cement with fly ash or oil shale ash.

All the strength results from the stage I is presented in Table 11.

Table 11. Honkasuo 28 and 90 d results from I stage.

Aggregate	Binder		Strength result [kPa]	
	quality	amount [kg/m3]	28 d	90 d
Peat mix 1:1 (Tv1 0.5-1.5 m and Tv2 1.5-2.5 m)	PlusCem	80	109	147
		110	185	194
		140	230	
	SRCem	80	176	
		110	194	
	PlusCem + FA	70+100	123	122
		70+200	100	102
		90+100	134	139
		90+200	112	
		110+100	172	
	SRCem + FA	90+100	169	173
	PlusCem + OSA8	70+100	84	94
		70+200	154	
		90+100	113	122
Tv1 (Pt 127 / 0.5-1.5 m)	PlusCem	110	238	257
	SRCem	110	282	
	PlusCem + FA	90+150	213	220
Tv2 (Pt 127 / 1.5-2.5 m)	PlusCem	110	119	125
	SRCem	110	127	133
	PlusCem + FA	90+150	81	90
Tv 2 (Pt 127/1.5-2.5 m) + Lj (Pt 127 / 4-5 m) 2:1	PlusCem	80	78	88
		100	119	134
		120	163	
	SRCem	100	136	
	PlusCem + FA	70+100	69	75
		70+200	77	
		90+100	104	109
	PlusCem + OSA8	70+100	139	151
Tv 1 (Pt 127 / 0.5-1.5 m) + "Clay2" 2:1	PlusCem	80	131	138
		100	155	184
	PlusCem + FA	70+150	113	135
		90+100	148	200
	PlusCem + OSA8	70+100	256	
IjSa (Pt 127 / 4-5 m)	PlusCem	60	112	138
		80	223	
		100	326	
	SRCem	60	164	
	PlusCem + FA	40+100	53	66
		40+200	42	52
		60+100	127	155
	PlusCem + OSA8	40+100	148	202

Stage II results

On the basis of the stage I, the studies continued with the most potential binder options in the next stage. The studied sample points were Pt 128 and 129. The binders used were SR-Cem and a mixture of SR-Cem and fly ash. Also, the impact of the ash quality was tested by using oil shale ash.

As the quite thin peat layer in sample point Pt 128 will be mixed during the stabilisation work anyway with the lower clay, the laboratory tests were done with the mixture of peat and clay in portion of 2:1. This describes especially the situation in the lower part of the layer to be stabilised.

In sample point Pt 129 the peat quality doesn't change significantly vertically, so the studies were made by using peats from different layers in portion of 1:1 as an aggregate. Under the peat is moraine which cannot be mixed to the layer to be stabilized, so moraine was not included in the laboratory tests at all. In sample point Pt 129 also the impact of wetting the peat to the strengthening was studied, as the peat samples delivered to the laboratory were very dry.

Stage II results for the sample point Pt 128 are presented in Figure 18.

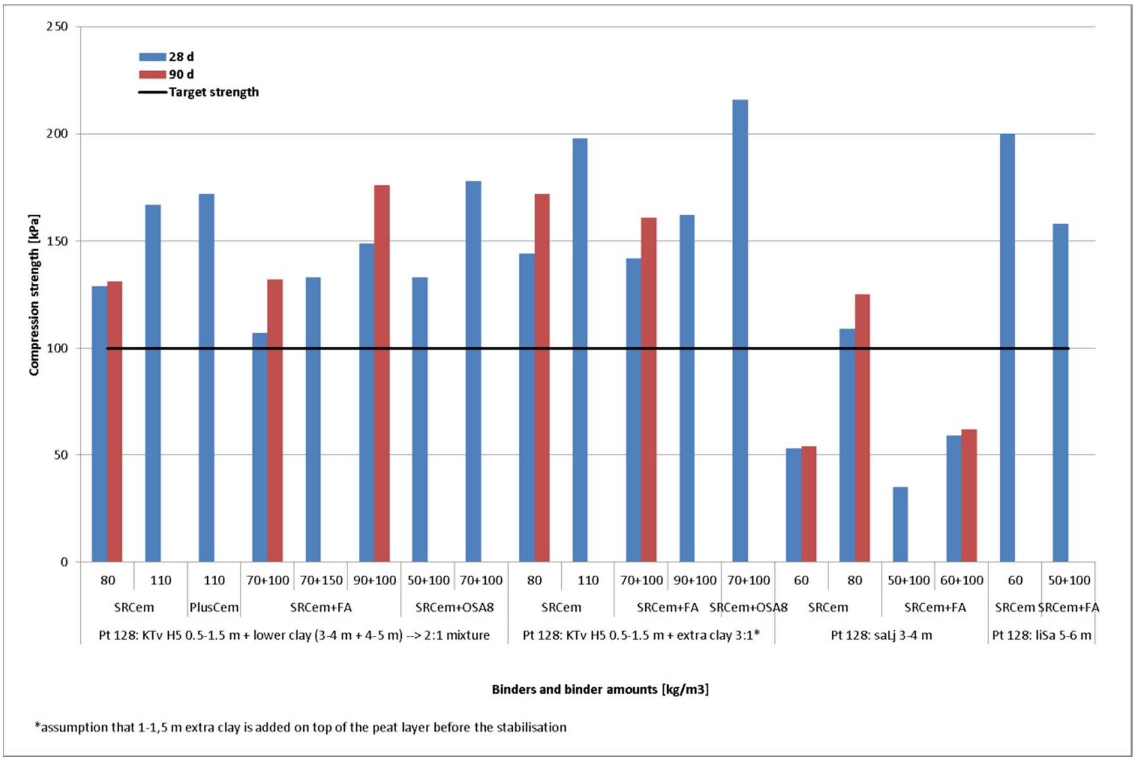

Figure 18. 28 and 90 d results for Pt 128.

According to the stabilisation test results, the following conclusions can be made:

- When lower clay was mixed with the peat (Pt 128), all the studied binders and binder mixtures cured to the target strength (100 kPa) in 28 days. When using fly ash in the binder mixture, the long-time curing is stronger than while using only cement.
- Oil shale ash gave clearly better results than fly ash.

The results of the sample point Pt 129 are presented in Figure 19.

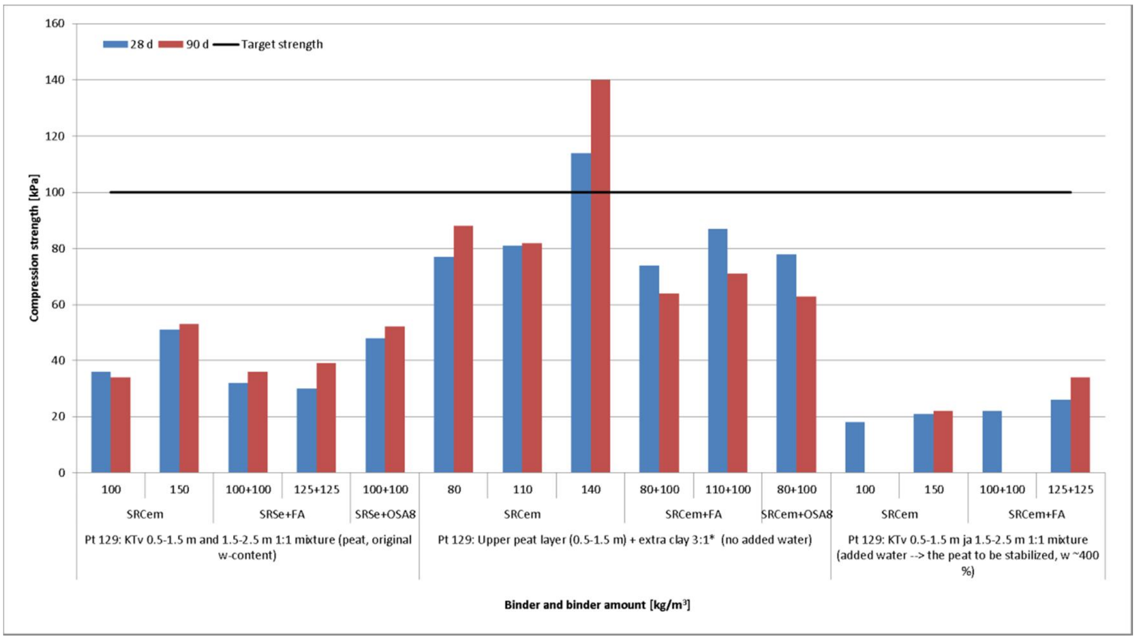

Figure 19. 28 and 90 d results for Pt 129.

The dry peat sample from Pt 129 cured very poorly. Extra strength was not achieved even by adding fly ash or oil shale ash to the binder mixture. Adding water (-> 400 %) to the dry peat before adding binder did not improve the situation either – the strength results were even lower than for the original water content (200 %).

When extra clay was added to the peat in ratio of 3:1, the strength results got clearly better. The amount of SR-Cem required in order to reach the target level decreased to the level of 120-130 kg/m^3.

All the strength results from stage II are presented in Table 12.

Table 12. Honkasuo 28 and 90 d strength results from II stage.

Aggregate	Binder		Strength result [kPa]	
	quality	amount [kg/m3]	28 d	90 d
Pt 128: KTv H5 0.5-1.5 m + lower clay (3-4 m + 4-5 m) --> 2:1 mixture	SRCem	80	129	131
		110	167	
	PlusCem	110	172	
	SRCem+FA	70+100	107	132
		70+150	133	
		90+100	149	176
	SRCem+OSA8	50+100	133	
		70+100	178	
Pt 128: KTv H5 0.5-1.5 m + extra clay 3:1*	SRCem	80	144	172
		110	198	
	SRCem+FA	70+100	142	161
		90+100	162	
	SRCem+OSA8	70+100	216	
Pt 128: saLj 3-4 m	SRCem	60	53	54
		80	109	125
	SRCem+FA	50+100	35	
		60+100	59	62
Pt 128: liSa 5-6 m	SRCem	60	200	
	SRCem+FA	50+100	158	
Pt 129: KTv 0.5-1.5 m and 1.5-2.5 m 1:1 mixture (peat, original w-content)	SRCem	100	36	34
		150	51	53
	SRSe+FA	100+100	32	36
		125+125	30	39
	SRSe+OSA8	100+100	48	52
Pt 129: KTv 0.5-1.5 m + extra clay 3:1 (no added water)	SRCem	80	77	88
		110	81	82
		140	114	140
	SRCem+FA	80+100	74	64
		110+100	87	71
	SRCem+OSA8	80+100	78	63
Pt 129: KTv 0.5-1.5 m and 1.5-2.5 m 1:1 mixture (added water --> the peat to be stabilized, w ~400 %)	SRCem	100	18	
		150	21	22
	SRCem+FA	100+100	22	
		125+125	26	34

5. Leaching test results

5.1 Dog Park leaching test results

Leaching tests were carried out for the surplus soft soil masses to be used in the Dog Park area. The soils were stabilised with different binders in order to find out the leaching properties of the stabilised soils. The basic data about the surplus soil is presented in Table 13.

Table 13. Geotechnical properties of the surplus soil sample

Sample	Water content [%]	Density [kg/m^3]	Loss of Ignition LoI [%]	Soil quality
Dog Park (8.3.2012) 1-	93.5	1480	3.6	Clay

2 m				

Cement (Cem), lime (CaO), fly ash (FA) and sulphur removal product (deSox) were used as binders in the stabilisation process of the soil. The leaching tests were performed for the samples presented in Table 14 by modified diffusion test.

Table 14. The modified diffusion test specimens and used binders.

Sample	Binders	Binder amount [kg/m^3]
PU-1A	Cem + FA	60+100
PU-2A	CaO+Cem+deSOx	18+42+50
PU-3A	Cem	80
PU-4A	-	-

The results of the pH and electrical conductivity measurements are presented in Table 155. The pH's of the water samples of the stabilised specimens are clearly higher than the ones of the non-stabilised specimen.

Table 15. The pH and electrical conductivity values of the water samples

Sample	Binders [kg/m^3]	Days from starting the test [d]	pH	Electrical conductivity +25 °C [mS/m]
PU-1A	Cem+FA 60+100	4	9.6	4.2
		14	9.4	7.3
		66	8.9	14.0
PU-2A	CaO+Cem+deSOx 18+42+50	4	10.2	24.4
		14	9.8	41.6
		66	9.2	76.7
PU-3A	Cem 80	4	10.0	6.4
		14	9.9	9.4
		66	9.7	18.4
PU-4A	-	4	8.3	3.2
		14	8.0	5.2
		66	8.0	11.9

The total concentrations and the leaching of harmful substances in the non-stabilised clay specimen are presented in Table 166. The values are compared to the natural concentrations in clays in the area (Tarvainen, 2012). The results show that the used clay has the typical concentration values of the clays in the area.

Table 16. The total concentration and leaching of the harmful substances – Dog Park surplus clay.

Substance	Dog park (8.3.2012) 1-2 m		Espoo, subsoil, clay*	
	Total concentration	Leaching	Natural background concentration (median)	Natural background concentration (maximum)
	mg/kg dry	mg/m^2/64 d	mg/kg dry	mg/kg dry weight

	weight		weight	
Antimony	<0.5	<0.4	0.195	0.370
Arsenic	9.9	<0.9	9.67	14.3
Barium	300	10	201	303
Mercury	<0.1	<0.1	0.007	0.127
Cadmium	<0.2	<0.1	0.100	0.260
Chromium	110	<0.9	78.1	113
Copper	52	1.4	32.0	75.8
Lead	15	<0.4	15.3	24.6
Molybdenum	<2	<0.9	0.93	2.05
Nickel	52	<0.9	36.7	61.6
Selenium	<1	<0.9	0.400	0.580
Zinc	160	17	100.0	157
Vanadium	120	<0.9	93.9	142

*Tarvainen, T., 2012, Espoon maaperän taustapitoisuudet, GTK

The results were compared with the Dutch guideline values for solidified materials in two different classes; 1A (permanently moist deposit) and 1B (unisolated occasionally moist deposit). The results were also compared with the Finnish guideline for the maximum values for solidified materials which have maximum of 0.7 m layer depth (Sorvari, 2000). The results of the modified diffusion tests carried out for the stabilised specimens showed that:

- The leaching of arsenic, mercury, cadmium, chromium, lead, nickel, selenium and vanadium were below the determination limit of the analysis.
- The leaching of fluoride, sulphate, barium, copper, molybdenum and zinc were clearly below the Dutch and the Finnish guidelines values.
- There is no guideline value for DOC but the solubilities were close to the determination limit of the analysis.
- The leaching of chloride was elevated in the specimen in which CaO+Cem and deSOx were used as the binder mixture agents. The higher solubility results from the deSOx which has a high chloride content. The leaching of chloride was below the guideline limits in all the other specimens.
- The leaching of antimony was above the Dutch guideline limit in the specimen where the CaO+Cem and deSOx were used as the binder mixture and in the specimen where only cement was used. The solubility values were however below the Finnish guideline value.

The solubility values are presented in the following figures (20-27).

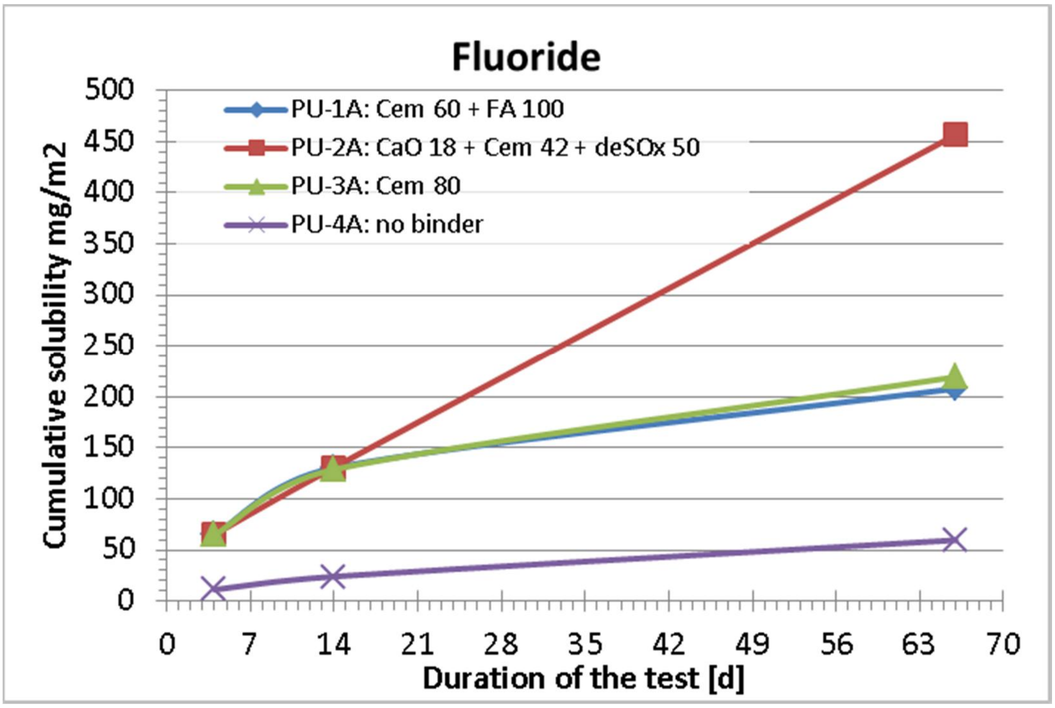

Figure 20. Cumulative leaching of fluoride with different specimens. (Dutch guideline value 4400 mg/m^2 and Finnish guideline value 2800 mg/m^2)

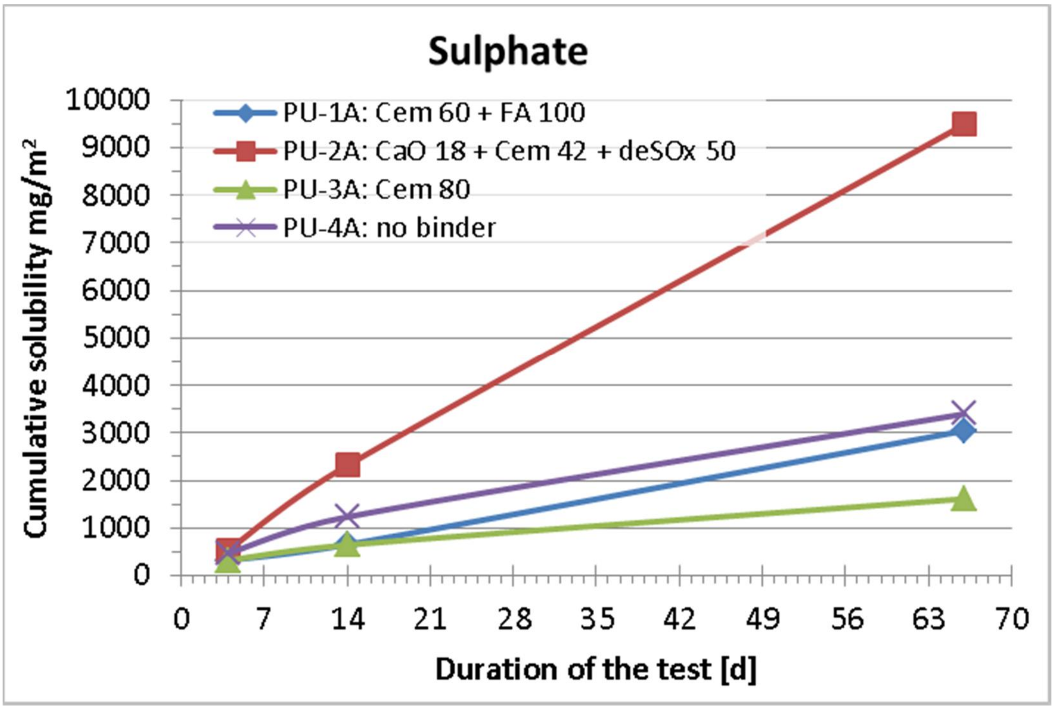

Figure 21. Cumulative leaching of sulphate with different specimens. (Dutch guideline value for 1B 80 000 mg/m^2)

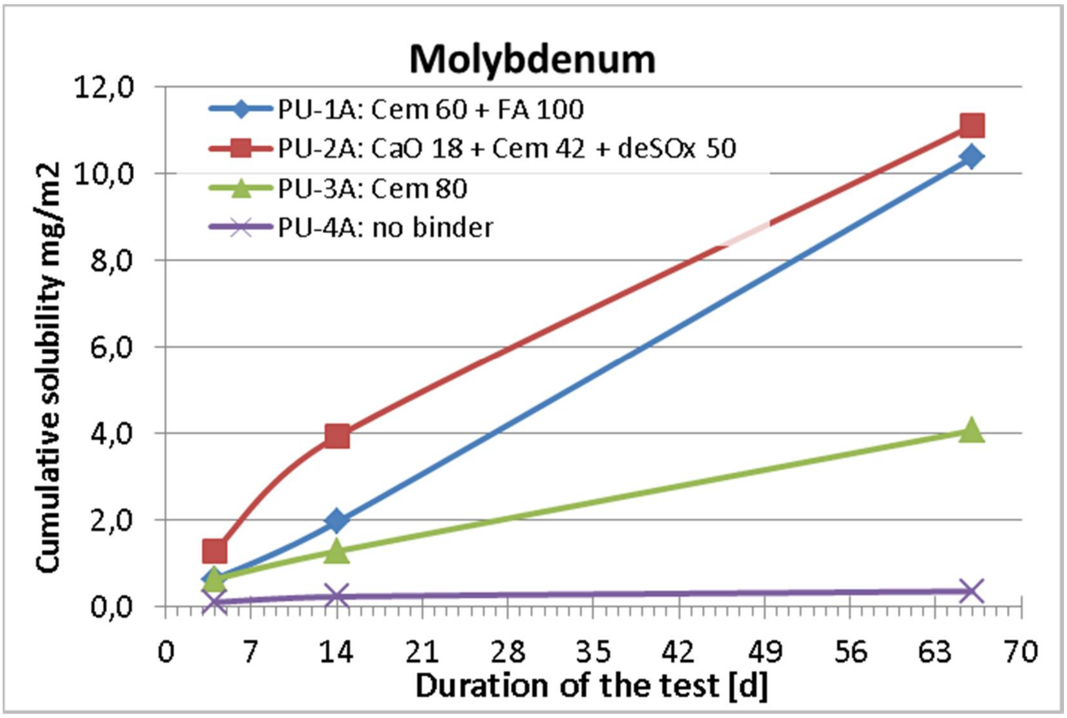

Figure 22. . Cumulative leaching of molybdenum with different specimens. (Dutch guideline value for 1B 48 mg/m^2 and Finnish guideline value 70 mg/m^2).

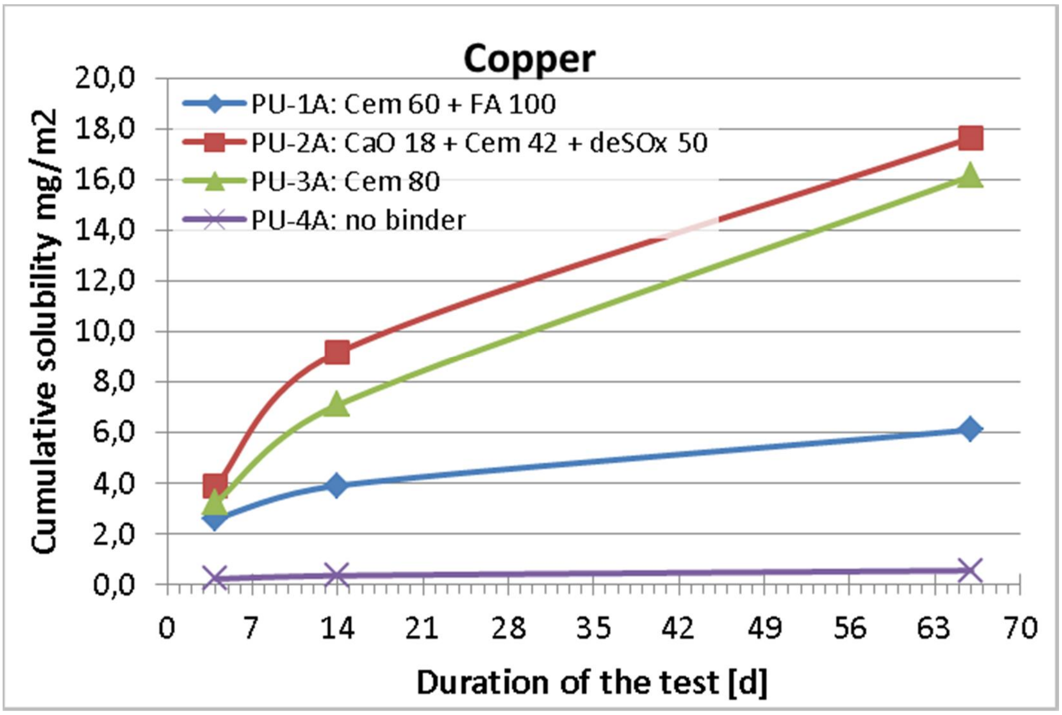

Figure 23. Cumulative leaching of copper with different specimens. (Dutch guideline value for 1B 170 mg/m^2 and Finnish guideline value 250 mg/m^2)

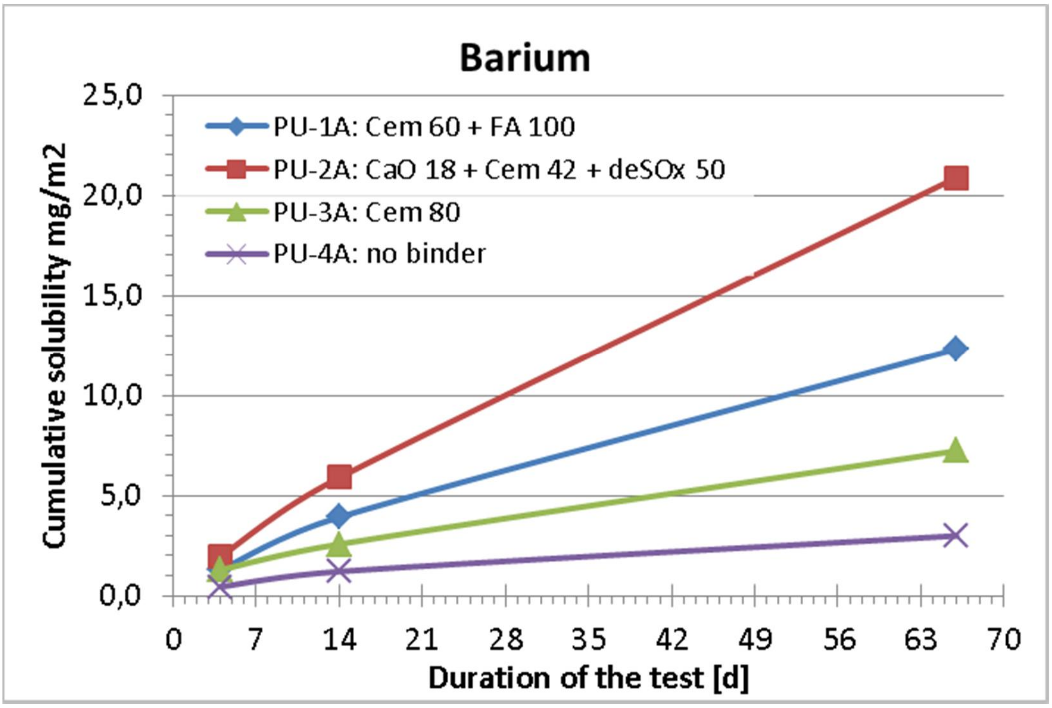

Figure 24. Cumulative leaching of barium with different specimens. (Dutch guideline value for 1B 2000 mg/m^2 and Finnish guideline value 2800 mg/m^2)

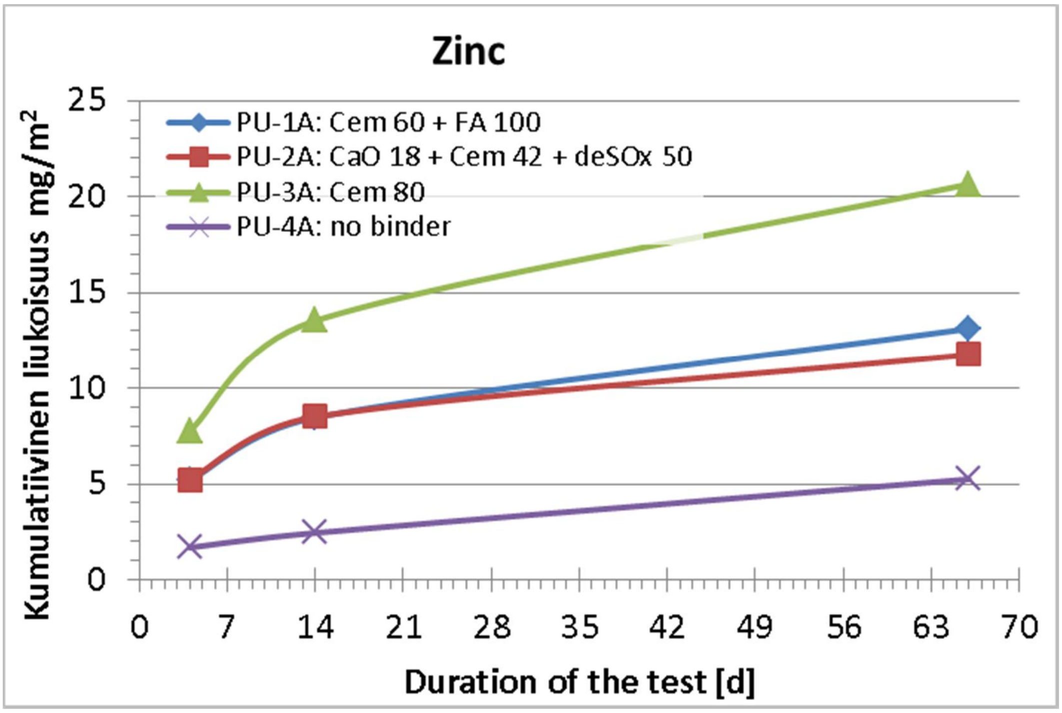

Figure 25. Cumulative leaching of zinc with different specimens. (Dutch guideline value for 1B 670 mg/m^2 and Finnish guideline value 330 mg/m^2)

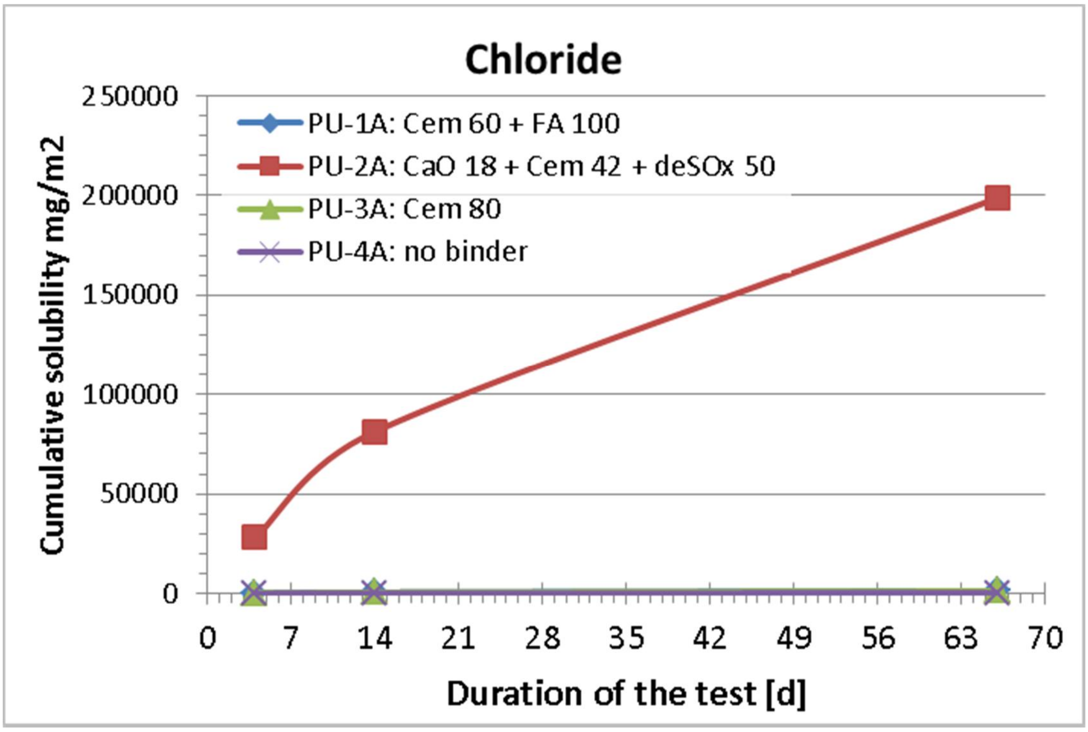

Figure 26. Cumulative leaching of chloride with different specimens. (Dutch guideline value for 1B 54 000 mg/m^2)

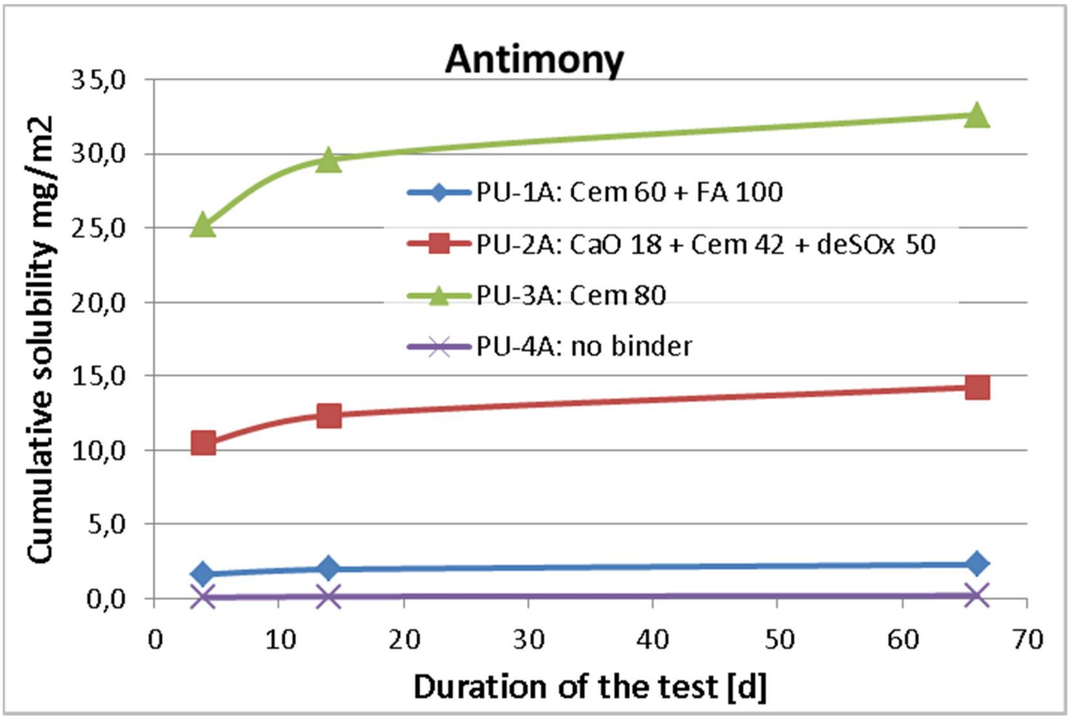

Figure 27. Cumulative leaching of molybdenum with different specimens. (Dutch guideline value for 1B 12 mg/m^2)

5.2 Jätkäsaari leaching test results

Leaching of the Jätkäsaari materials was studied by modified diffusion test in spring 2014. The binders used in the test were cement, lime, fly ash from the Hanasaari power plant (Helsinki), desulphurisation agent and oil shale ash from the Eesti Energy power plant (Estonia).

Table 17. Aggregates, binders used in the modified diffusion test and water permeability values of the samples.

Sample	Aggregate	Water content [%]	Binder and binder amount [kg/m^3]	Water permeability k [m/s]
JHL-1	5/13 0-3 m mixture	100	PlusCem + FA 50+150	1,1 x 10^{-9}
JHL-2	7/13 1-2 m	57	PlusCem + FA 50+150	7,4 x 10^{-10}
JHL-3	mixed sample*	95	PlusCem + FA 50+150	1,7 x 10^{-9}
JHL-4	mixed sample*	95	PlusCem + FA + deSOx 50+150	1,1 x 10^{-9}
JHL-5	mixed sample*	95	KC 3:7 + FA 50+150	1,2 x 10^{-9}
JHL-6	mixed sample*	95	KC 3:7 + FA + RPT 50+75+75	1,1 x 10^{-9}
JHL-7	mixed sample*	95	OSA8 150	8,2 x 10^{-10}

*mixture of samples 1/13, 4/13 and 5/13

The diffusion test results were compared to the limit values given in the environmental permit application (see Table 16).

Table 18. Limit values presented in the environmental permit application.

Element	Limit value [mg/m^2]
Arsenic, As	58
Barium, Ba	2800
Cadmium, Cd	2,1
Cobalt, Co	280
Copper, Cu	250
Mercury, Hg	1,6
Molybdenum, Mo	70
Nickel, Ni	270
Lead, Pb	210
Antimony, Sb	36
Selen, Se	14
Tin, Sn	280
Vanadium, V	700
Zinc, Zn	330
Fluoride, F	2800
Sulphate, SO4	162 500
Chloride, Cl	162 500

None of the tested samples did exceed the presented limit values. On the contrary, all the solubility value results were very low. Many of the tested solubility values stayed also below the laboratory determination limit. Also all the water permeability values fills the required value of $k<1x10^{-8}$ m/s.

6. Conclusions

On the basis of the material tests, applicable materials were found for each pilot and thus the ABSOILS project objective – the utilisation of surplus soils in various civil engineering applications – was met.

All the structures carried out in the framework of the Absoils project had at least as good technical performance as conventional structures.

Mass stabilisation is a feasible method for the stabilisation of soft clays and contaminated and clean soft sediments and for the utilisation of stabilised masses.

The stabilisation technology requires technical and environmental material tests in the laboratory before the launch of construction works and follow-up studies afterward.

Technical properties of the materials are determined by laboratory studies including compression strength tests after a specified curing time. Several different binders and their amounts are tested in order to determine a suitable binder mixture for a given application.

The most commonly applied binder in stabilisation has so far been cement. However, its high price and its considerably high carbon footprint encourage searching for alternative solutions. The replacement of cement with binders based on secondary materials such as e.g. fly ashes, FGD or oil shale ash in the stabilisation of soft clays and dredged sediments has been studied both in the laboratory and on site with the Absoils project pilot applications.

Several kinds of industrial by-products are applicable in binder mixtures. These products make the method more economic and environmentally friendly.

The environmental acceptability is evaluated by testing leaching of contaminants from the stabilised material in the laboratory. The results of the tests provide good reasons for the use of industrial by-products as binder components in the process of stabilisation of soft clays and dredged sediments.

Due to considerable variations in quality of the mass stabilised sediments, the need for an active quality control in all stages of work is indispensable.

Based on the results of the Materials Action and the experience obtained during carrying out the Piloting Action, it has been proved that the use of surplus soils, waste materials and by-products as construction material is technically and environmentally feasible.

Several applications for the utilisation of stabilised soft clays and sediments have already been developed but it is still possible to find new potential applications.