The Use of Paper Industry Side Products in Construction

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Abstract The amount of waste material and side products of various industrial plants is increasing, which leads to waste accumulation and lack of space in disposal landfills. The paper industry, with its side products of paper sludge and ash, faces these same issues. To reduce the accumulation of these materials, we explored the possibility of their use in construction. First, a series of geomechanical tests was conducted on a product consisting of fly ash and bottom ash. Based on the laboratory results, test fields were constructed, where the preparation and installation technologies were tested. The fields were exposed to atmospheric conditions, so durability of the product in the natural environment was proven. Since the composition of both fly ash and bottom ash depends on the paper industry process, continuous monitoring of their characteristics was established.

Keywords: waste management, municipal waste, waste composition analysis, waste treatment, waste composition analysis methodology.

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1 Introduction

Side products of various industrial plants are increasing, which leads to waste accumulation and lack of space in disposal landfills. The same effect is noticeable for the paper industry. The main side product is paper ash, which is a residue from burning material. Normally, ash (paper, coal, etc.) is used in mixtures with soil for stabilisation of various road or embankment layers (Vestin *et al.*, 2012). Sometimes fly ash mixed with clay is used for covering the layers in a landfill, so that a less permeable material is attained (Magnusson, 2005; Toller *et al.*, 2009). In this research, a product prepared only from paper ash is used as the material for embankments and backfill material in geomechanical structures. The use of natural material, from a natural source, in such a case is minimised to zero, and the use of a side product like waste material is maximised. The study was conducted from the engineering point of view.

2 Methods and Material

The study demonstrates the design process for a new product created from a paper industry side product. It includes all the laboratory tests and field measurements necessary before the required documentation for using the products in construction can be issued, as well as the extent of quality control during the construction work.

2.1 Preliminary investigations

A side product from paper industry called paper ash includes 20 % of paper fly ash and 80 % of paper bottom ash by dry mass and was first tested in the laboratory. The parameters for in-built products in structures like embankments or backfill were established with basic geomechanical tests to determine water content (according to standard SIST EN ISO 17892-1:2015) and the Proctor test (according to standard SIST EN 13286-2:2010/AC:2013). The Proctor test, which determines maximum dry density and optimum water content, is one of the most important tests for all embankment or backfill materials. The mineralogical characteristics of the material also need to be defined in the first step. The mineralogical composition of a material is important for predicting its environmental impact, which was later tested with a leaching test. For this, the product was prepared according to the Proctor results, and the leaching test was performed according to standard SIST EN 1744-3:2002, with chemical analyses following the standards ISO 17294-2:2016(E), SIST EN ISO 12846:2012, ISO 10359-1:1992 and SIST EN ISO 10304-1:2009. When the results of chemical analyses on leaching water reached values lower than critical values according to the document Acceptability of Alternative Materials in Road Construction, Environmental Assessment, Appendix 3 – Limit Values associated with Level 1 Environmental Characterisation, Table 1., column 1., Sétra, France, February 2012, further geomechanical tests were performed. For this material, paper ash, with predicted use as backfill or embankment material in geotechnical structures, shear properties, deformation properties, compression strength and water permeability characteristics needed to be tested. Because these parameters are dependent on the dry density of the material, it is necessary for the samples for geomechanical testing to be prepared at the defined dry density and water content. This means under conditions that correspond to the construction conditions.

2.2 Preliminary test fields

The test fields were planned with all results from the laboratory preliminary tests, to investigate the preparation of the product and the installation process. Three different test fields were constructed with different types of mixing and compaction machinery. The main differences between the test fields concerned the time when the paper ash was installed after mixing: immediately, after 4 hours or after 24 hours. The most useful machinery for mixing the paper ash with water and the compactor for compacting it were determined from the results of field measurements and practical experience. After the test fields were made, field measurements such as water content and density were performed, using a nuclear gauge and strength, using a lightweight deflectometer. Intact samples were also taken for additional laboratory testing: water content and density for the geotechnical part and a leaching test for the chemical/environmental part.

Figure 1: One of the test fields with the compactor.

2.3 Activities while building the structures

All data from preliminary laboratory and field tests was used to prepare the Slovenian National Technical Approval (STS). With this document, the product, paper ash, can be used in construction. The main parameters as well as the procedure to prepare the product and the structures into which it was built are defined in the document. The STS also includes a control plan for the product in the section on preparation, as well as field measurements during construction work and while incorporating the paper ash in layers of embankment or backfill. Regular control of paper ash includes particle size distribution tests, Proctor tests and uniaxial compression tests, and ensures a homogenous product, which leads to homogenous layers. The right machinery also needs to be used for correct installation of paper ash as a compacting material. With field measurements, prescribed by the STS, the criteria for good compaction of layers were checked, and intact samples of in-built paper ash were taken to perform tests of environmental impact – leaching tests.

2.4 Description of the material: paper ash

Paper ash is a burning residue in the boiler, where deinking paper sludge, bark and wood residue from production are burned. Paper ash consists of bottom ash (80 % by dry mass) and fly ash (20 % by dry mass). Fly ash is a dust, with a particle size up to 1 mm, while bottom ash represents grain agglomerates of ash up to 10 mm. The chemical and mineral compositions are similar. Most of the components are in an amorphous phase. Calcite, lime, portlandite and other minerals in minor quantities represent the crystalline components.

Table 1: Main parameters for paper ash.

Initial Moisture Content, w (%)	0
Specific Gravity, ρ_s (Mg/m^3)	2.64
Optimum Moisture Content, w_{opt} (%)	51
Maximum Dry density, ρ_{dmax} (Mg/m^3)	0.99
Uniaxial compression strength, Rc (MPa)	0.58
Friction angle after 28 days, f (°)	33
Cohesion after 28 days, c (MPa)	0.5
Particle size distribution	
Gravel content (> 2,0 mm) (%)	0
Sand content (0,063 – 2,0 mm) (%)	13.3
Silt content (0,002 – 0,063 mm) (%)	75.6
Clay content (< 0,002 mm) (%)	11.1

The chemical composition of the paper ash was determined by using a Thermo Scientific ARL PERFORM'X Wavelength Dispersive X-Ray Fluorescence Spectrometer (WD XRF).

Table 2: Chemical composition of paper ash.

	Chemical components	**%**
SiO_2	**Silicon dioxide**	11.37
Al_2O_3	**Aluminium oxide**	8.26
Fe_2O_3	**Iron (III) oxide**	0.39
CaO	**Calcium oxide (lime)**	47.94
P_2O_5	**Phosphorus pentoxide**	0.17
MgO	**Magnesium oxide**	1.70
K_2O	**Potassium oxide**	0.27
Na_2O	**Natrium oxide**	0.17
TiO_2	**Titanium dioxide**	0.18
SO_3	**Sulfite**	0.31
LOI		27.26
Cl^-	**Chloride**	0.065

3 Results

Preliminary laboratory results are shown in Table 1 and Table 2. Results from the preliminary test fields as well as a comparison between results from the test fields and the structure, an embankment, are shown in this chapter.

Table 3 shows results from measuring water content and dry density by nuclear gauge in all three test fields. The main differences between the test fields concern the time elapsed between mixing the paper ash with water and compaction of the material in embankment layers. Each test field was constructed in three 20 cm layers. For the mixing step, special machinery was used, containing a spiral in the excavator spoon. The mixing process, in which the paper ash was mixed with water to the optimum water content, lasted at least 15 minutes. With this process, a homogenous product was prepared. After being mixed, the product was spread into a layer and compacted with a vibrating plate to the correct dry density. For test field No. 2, compaction was done after 4 hours, and for test field No. 3 after 24 hours. For test field No. 3, material was mixed again with additional water, before it was compacted into layers. Dry density and water content were measured for each layer, and intact samples were taken from the final layer. The dynamic deformation modulus was measured on the surface of last layer at different time periods.

Table 3: Results from the test fields.

Test field No.		**1**	**2**	**3**
Compaction		**immediately**	**after 4 hours**	**after 24 hours**
Average water content (%)	**Immediately**	57.4	35.3	55.1
	After 24 hours	48.1	/	52.0
	After 28 days	40.7	24.0	38.7
Water content, laboratory (%)	**Immediately**	49.9	39.0	51.4
Average dry density (Mg/m^3)	**Immediately**	0.99	0.96	0.98
	After 24 hours	1.02	/	1.00
	After 28 days	1.02	0.99	1.01
Dry density, laboratory (Mg/m^3)	**Immediately**	0.98	0.96	0.94
Dynamic deformation modulus (MPa)	**Immediately**	8.1	17.4	21.3
	After 28 days	> 70	33.2	> 70

The results show that the dry density in the first and the third test fields are similar, but it is necessary to know that for the third test field, the material was remixed with additional water. That is also why measured water contents are similar. The results for the second test field show lower dry densities as well as lower water content. If the dry density is compared to the results of the Proctor test, it can be concluded that with the correct process of mixing and compaction, at least 96 % compactness was reached. The dry density increased slightly after 24 hours and 28 days, while the water content dropped by approximately 10 %.

The influence of the binding process is more apparent in the difference between the dynamic deformation moduli (*E*vd). While values are low immediately after compaction, they reached more than 70 MPa after 28 days. The exception is test field No. 2, where after 28 days, the dynamic deformation modulus reached values more than 2 times greater. The reason for such behaviour of paper ash could lie in the binding process, which mostly expires in the time between the mixing and compacting steps.

Results of chemical analysis of the leached water sample from the test fields (Table 4) shows that all the values were below critical.

Table 4: Chemical analyses of the leached water.

Element	Unit	Critical value	Laboratory sample	Sample from test field
Arsenic (As)	mg/kg d.m.	0.5	<0.001	<0.02
Barium (Ba)	mg/kg d.m.	20	2.73	2.6
Cadmium (Cd)	mg/kg d.m.	0,04	<0.002	<0.005
Chromium-all(Cr)	mg/kg d.m.	0.5	0.028	<0.01
Copper (Cu)	mg/kg d.m.	2.0	0.035	0.20
Mercury (Hg)	mg/kg d.m.	0.01	<0.001	0.0021
Molybdenum (Mo)	mg/kg d.m.	0.5	0.025	<0.05
Nickel (Ni)	mg/kg d.m.	0.4	<0.002	<0.01
Lead (Pb)	mg/kg d.m.	0.5	<0.005	<0.05
Antimony (Sb)	mg/kg d.m.	0.06	0.002	<0.006
Selenium (Se)	mg/kg d.m.	0.1	<0.003	<0.01
Zinc(Zn)	mg/kg d.m.	4.0	<0.005	<0.1
Chloride (Cl^-)	mg/kg d.m.	800	81.4	11.7
Fluorite (F^-)	mg/kg d.m.	10	<1	<1
Sulphate (SO_4^{2-})	mg/kg d.m.	1000	<10	11.9

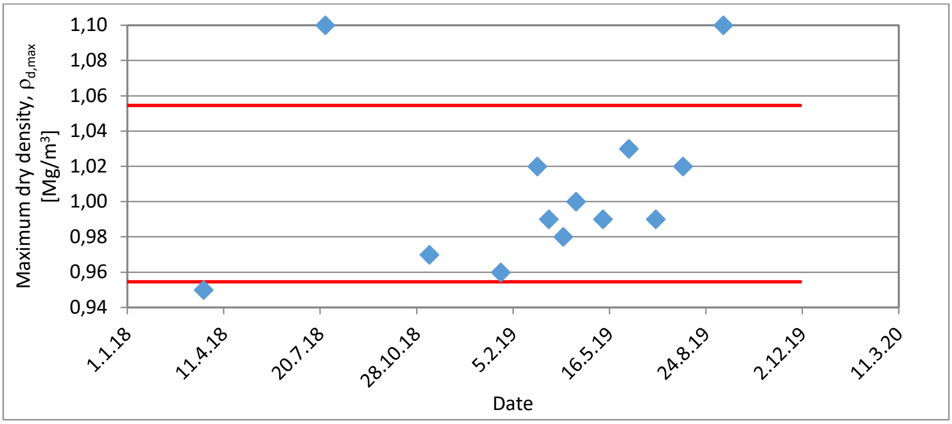

Figure 2: Results from controlling the maximum dry density.

The regular control of paper ash, which includes particle size distribution, Proctor tests and uniaxial compression tests, shows that over the period of one year, all the results are quite similar, mostly in the interval of allowed tolerance (Fig. 2 – Fig. 4).

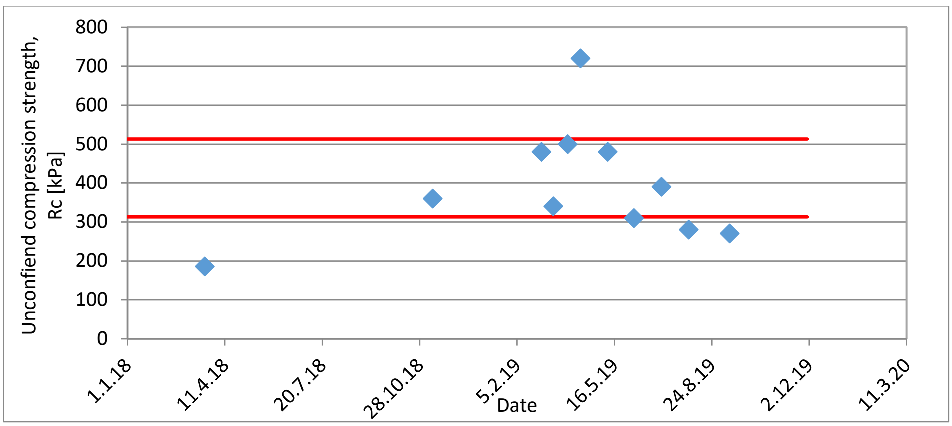

Figure 3: Results from controlling the unconfiend compression strength.

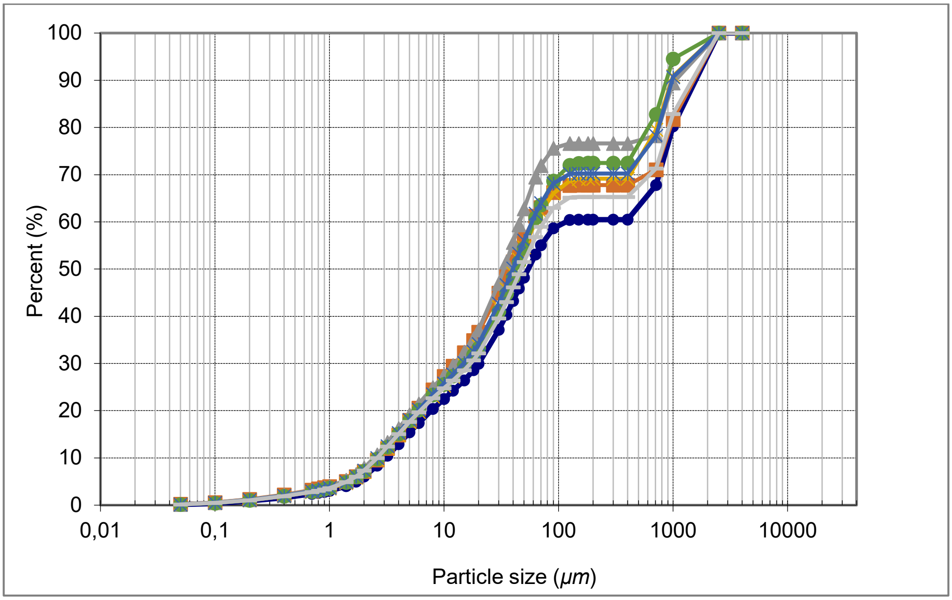

Figure 4: Results from controlling the particle size distribution.

4 Conclusions

Paper ash, which is a side product of the paper industry, can be used for embankments and as a backfill material in geotechnical structures. However, several laboratory tests and field measurements should be performed before this material is used as a product. The main purpose of the whole process is to define the technology for preparing the right mixture and the right compaction technique to reach the requirements for embankment layers, such as density, water content etc., as well as the requirements for environmental acceptability. With all the preliminary investigations done and the Slovenian National Technical Approval issued, the product needs to be continuously controlled both in a laboratory and in the field during the construction work. Only with quality work and continuous control, it is possible to attain a homogenous product for environmentally friendly and geotechnically acceptable structures.

Paper ash is a light material (twice as light as gravel), with high compression strength and shear parameters, which is great for use in areas where the natural ground has low bearing capacity.

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