

ENVIRONMENTAL AND MECHANICAL ASSESSMENT OF WOOD FLY ASH USED FOR STABILISATION OF GRAVEL ROADS

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SUMMARY: Due to climate change, there is a growing demand for mechanically stabilising forestry roads in Sweden. One way to do this is by addition of cement to the bearing layer of the road. In this study, cement was replaced by a forestry industry fly ash. Mechanical testing showed that a good stabilising effect could be achieved and at a 30% ash addition, it could resist more than 12 freeze-thaw cycles. The environmental impact of the ash addition was assessed using a standard leaching test at a liquid to solid ration of ten. The results indicated that most constituents of the ash remained fairly stable, but that notably chloride, potassium, calcium and sodium was mobilised in the grams per kg of TS range, adding up to about 1 % of the total mass. This may cause an elevated salinity in the emediate vicinity of a road, e g in the ditches, under a short time period, but is not considered to be a major problem for recipients. The results also indicate that the total content is a poor estimate for the leachability of various elements.

1. INTRODUCTION

Large climate changes will be expected in sub arctic and arctic regions due to increased global average temperature. The winter period with temperatures below zero causing frost penetration of the ground will be reduced with several weeks in the central part of Sweden and the precipitation is expected to increase. This will affect the bearing capacity of e.g. gravel roads used for heavy timber transports by Swedish forest industries. The worst situation for the stability of gravel roads is when the temperature fluctuates around zero. Because the continuous frost period is expected to be reduced the quality of the roads must be improved by stabilisation.

Stabilisation of gravel roads can be done with geo textile, mesh of steel, grillage of timber or with cement but wood fly ash from the incineration of different types of bio-fuels can also be used. The bio-fuel fly ash is rich in Ca, Al and Si which gives it puzzolanic properties of different levels depending on the relationship between silicate minerals, calcium oxides and hydroxides. Fly ash mixed with the existing road material hardens through hydration and carbonation reactions and hence, the stability of the road will be enhanced.

The properties of wood fly ash materials vary a lot and depend on the type of bio-fuel used and on the construction of the incineration plant. Before an ash is used as a construction material it has to be characterized regarding mechanical and chemical properties and potential environmental impact.

In June 2009 a forest road near Timrå in the centre of Sweden was upgraded by mixing wood fly ash in the base course of stony gravel. Before use, the impact of the ash on the leaching of

contaminants from the road material and on the mechanical stability of the base course was assessed and the results are presented here.

2. MATERIALS AND METHODS

The wood fly ash used in this study originates from a bio-fuel incineration plant located at Ortviken paper mill near Timrå in the middle region of Sweden. The furnace is a fluid bed operated at 730 °C where bio-sludge, bark and fly ashes from a grate furnace (where mainly bark has been incinerated) is incinerated. The fly ash is stored dry after separation and has been sampled in increments on the conveyor leading from the storage to transport containers. The ash was analysed regarding its total inorganic element composition, total organic carbon, acid neutralization capacity, free calcium oxide content and through standardised leaching tests at L/S 10 L/kg TS.

Mixtures of fresh ash from the incineration plant and gravel mixed with finer materials, hereafter called road extract, RE, that was excavated from the road (ash versus RE at the ratio 20/80 or 30/70, respectively) were tested for optimum water content and density. Axial compression tests on specimens (both mixtures and 100% ash) were performed before and after accelerated hardening. Cured specimens of mixtures were also tested with compression tests after 12 freeze-thaw cycles. Curing was achieved by storing the specimens in an atmosphere of carbon dioxide at 100% air humidity and 30 °C for seven weeks.

3. RESULTS AND DISCUSSION

3.1 Environmental properties

The composition of the used ash is summarised in Table 1 and Table 2 and the leaching data in Table 3. As can be seen from Table 1, the sample taken had been kept dry until analysis.

Table 1. Major constituents and characteristics. Total content of metals given as oxides. All analyses were performed in triplicates as a minimum.

Variable	Unit	Value	Variable	Unit	Value
Total Solids, 105°C (TS)	%	99.9	SiO ₂	% TS	23.5±0.1
LOI, 550°C	% TS	0.69	Al ₂ O ₃	% TS	10.7±0.1
pH	-	13.2	CaO	% TS	35.7±0.4
Conductivity	mS/cm	10.6	Fe ₂ O ₃	% TS	6.35±0.51
Total carbon (TC)	% TS	2.42±0,16	K ₂ O	% TS	3.57±0.10
Total organic carbon (TOC)	% TS	1.85±0,16	MgO	% TS	2.13±0.02
Inorganic carbon (IC)	% TS	0.57±0,20	MnO	% TS	1.49±0.01
f-CaO (free Calcium)	% TS	7.0±0,1	Na ₂ O	% TS	1.14±0.02
ANC pH 8.3	mmol/g TS	5.29±0,10	P ₂ O ₅	% TS	3.08±0.02
ANC pH 4.5	mmol/g TS	9.52±0,22	TiO ₂	% TS	0.23±0.01
S	% TS	2.07±0,2	Sum	% TS	87.9± 05

More than 92% of the total mass was explained by the analytes given in Table 1. The ash was rich in Ca, Si and Al (255, 110 and 57 g/kg TS, respectively) and contained 7% free CaO. The ratio CaO/SiO₂ was 1.53 indicating that the material had puzzolanic properties (1.5 is considered to be a practical limit). The ash was alkaline with acid neutralization capacity 9.5 mmol/g

(pH 4.5). The TOC content was low (1.85%) which indicated a well incinerated ash. The TOC should really be interpreted as “total oxidisable carbon” since a standard TOC analysis can not separate organic carbon from elemental carbon. As has been shown with other ashes, about half or more of the measured TOC may in fact be elemental carbon (Kumpiene et al. 2011).

Table 2. Minor constituents. Metals and arsenic. All concentrations given as mg/kg TS, n = 3.

Element	Concentration	Element	Concentration
As	<3.15	Ni	42.9 ±1.7
Ba	2630 ±30	Pb	31.1 ±1.0
Be	<0.6	Sc	3.5 ±0.4
Cd	3.94 ±0.32	Sn	28.2 ±7.2
Co	10.17 ±0.56	Sr	650 ±7
Cr	58.2 ±6.7	V	25.5 ±0.8
Cu	76.3 ±3.5	W	<60
Hg	0.147 ±0.001	Y	8.02 ±0.27
Mo	<6	Zn	2130 ±50
Nb	<6	Zr	81.0 ±4.9

The Zn concentration was rather high (2130 mg/kg TS) and exceeded SEPA’s recommended level for waste products recycled as construction materials (Swedish Environmental Protection Agency, 2010). However, as can be seen in Table 3, the leaching of Zn (0.25 mg/kg TS) was much below the recommended level of 4 mg/kg TS.

Table 3. Comparison of total content and leaching of the fly ash with a typical soil of the area, a till (sometimes called moraine, i.e. a mixture of particle sizes and predominantly consisting of quartz, feldspar and clay minerals).

Element	Total content	Total content	Leaching CEN test	Leaching CEN test
	Ortviken fly-ash	Natural till	L/S10 Ortviken fly-ash	L/S10 Natural till
Unit	g/kg TS	g/kg TS	mg/kg TS	mg/kg TS
Al	56.6	66.4	3.65	8.99
Na	8.46	19.2	1000	12.3
K	29.6	25.2	6330	11.7
Mg	12.8	5.85	<0.9	20.6
Cu	0.078	0.020	<0.01	0.04
Zn	2.13	0.036	0.25	0.07

The total concentration of elements in an ash material is of minor importance for the potential environmental impact it may cause. Other factors such as mineral phases and organic content in the ash and also the surrounding geochemical environment are of much greater importance for the leaching properties. It is for example interesting to note that the natural soil will leach twice as much aluminium as the fly ash does, although the content of both materials is fairly similar.

Also copper, magnesium and as mentioned zinc leaches to a lesser degree from the fly ash than from the natural soil. The opposite is true for sodium, potassium and some other elements not presented in the table, such as calcium (leaches 2.8 g/kg TS) and chlorides (1.2 g/kg TS). Together with a pH of 13, the high salt concentrations may impact the immediate vicinity of the road for a short period, but carbonation will lower the pH and the salts will most likely be washed away and diluted to not harmful levels in the recipient. However, the recommended level

of 130 mg/kg TS (SEPA 2010) for chlorides are clearly exceeded initially.

3.2 Mechanical properties

The compression strength of fresh ash and RE mixtures was higher than for 100% RE, Figure 1. Curing of specimens increased the compression strength. The higher ash content in the specimens, the better strength development was obtained. After 12 freeze-thaw cycles the compression strength decreased a bit for specimens with 20% ash content. For the mixture with 30% fly ash the freeze-thaw cycles increased the compression strength which was not expected. One explanation could be that the curing of the specimen was not finished at the first measurement. The high compression strength of the test specimens indicates that no other stabilising agent than ash is necessary to use when up-grading the road.

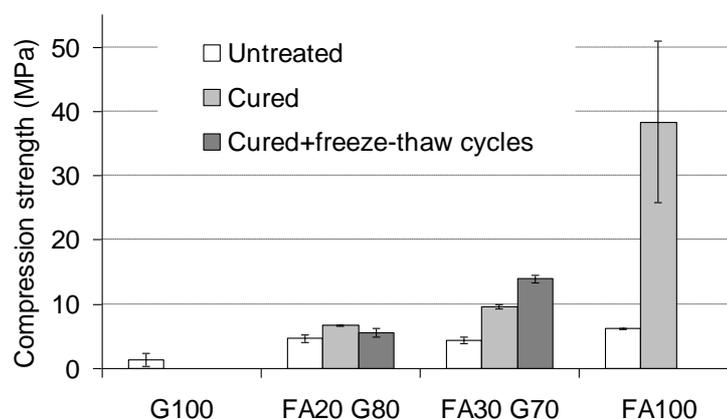


Figure 1. Compression strength for untreated specimens, cured specimens and cured specimens exposed to 12 freeze-thaw cycles. G100 denotes 100% RE, FA20 G80 denotes 20% fly ash and 80% RE, FA30 G70 denotes 30% fly ash and 70% RE, FA100 denotes 100% fly ash.

4. CONCLUSIONS

The cementitious properties of the fly ash makes it possible to substitute cement with pure ash, which saves energy consumption and emissions from cement production, and possibly also saves some money. The challenge is perhaps more to achieve the same consistent quality of material and handling of what can be achieved when using commercial cements. Obviously more ash than cement is needed.

From the environmental perspective, the elements present in the ash originated from the forest, so, the return of nutrients and minerals that has once been removed with the harvested trees should not change the environment much, but in a short time perspective there will be an elevation of some dissolved constituents in the soil adjacent to the road where the ash is applied. There is a need to assess the potential impact of this on a site specific basis and, since ashes will behave differently because of varying intrinsic properties, each ash needs a thorough characterisation before it is put to use. It is obvious from the comparison made in Table 3, that the total concentration of a substance gives little guidance regarding its mobility.

In this study, we have not paid attention to organic pollutants, given the low total carbon

content of the ashes, this may not be a serious oversight, but for some ashes, this could be important, in spite of the fact that many hazardous organic compounds may be strongly adsorbed to the bulk carbon phases. Another variable which could be important is the radioactivity, mainly due to the content of cesium 137.

It should also be remembered, that the standard leaching test is typically very far from any real leaching situation. Typically the leaching from a solid construction like a road would be orders of magnitude smaller than that of a standard leaching test. For non-reactive compounds like easily dissolvable salts, a standard leaching test may yield results within the same order of magnitude (often at the high end), but for many elements a much larger discrepancy may be at hand. Thus, it is essential to complement lab results with field observations.

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