

# Fly ash is enough for road stabilisation

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## Abstract

Sections of a gravel road in Sweden have been stabilised with fly ash. The aim of this study was to compare different stabilised road sections regarding density, homogeneity and stiffness and to evaluate the construction method.

Fly ash has pozzolanic properties and both laboratory and field studies showed that this fly ash was suitable for stabilising roads although the upgrading methods can be improved. The expected proportion of 30 % ash in the gravel layer was obtained in average but the obtained degree of compaction was in general too low. Increased amount of ash in the road seems to improve stiffness with time.

*Keywords: fly ash, gravel road, stabilisation, bearing capacity, homogeneity*

## INTRODUCTION AND AIM

Every year, mainly during soil frost thawing periods, many gravel roads in Sweden suffer from reduced bearing capacity which is to a large extent influenced by temperature and precipitation. With a climate change that leads to increased annual temperatures and rainfalls soil frost periods will become shorter which will further lead to less bearing capacity and more settlements and rutting in gravel roads. This will have consequences for the forest industry, one of the major industries in Sweden, which requires accessible forest roads main part of the year. To avoid the reduced bearing capacity, the roads may be stabilised.

Fly ash has in earlier project been used for stabilising roads both in Sweden and in other countries [1]. The fly ash contains mainly calcium and silicate oxides and has thus pozzolanic properties which give high compression strength and high bearing capacity [2]. Wood fly ash has also in earlier projects improved the frost-thawing properties and the bearing capacity of roads [3-7]. These properties can be enhanced by adding additives like cement or calciumoxide [8-10] but this also increases the costs for the production. It is therefore desirable that the hardening properties of the ash are optimally used so that the constructions can be built without using other additives besides the ash.

In spring 2008, Swedish Forest Agency together with Swedish Geotechnical Institute (SGI) and Luleå Technical University (LTU) therefore initiated a three year project, with the general aim to analyse and compile methods for adapting forest roads to climate change. Within the project, part of a forest road was upgraded and stabilised with fly ash from a local paper mill and ash stabilised test sections regarding stiffness and environmental impact.

This paper describes a complementary study, which was performed to examine how the construction methods could be improved so that the hardening capacity of the fly ash is optimally used and that no other additives would be necessary. For this purpose, two sections stabilised with different amount of ash were investigated after construction, regarding homogeneity, compaction and bearing capacity.

## MATERIALS

The fly ash used in the road was produced at the paper mill Ortviken in Sundsvall. The ash is derived from a fluidized bed incinerator and the fuel is mainly bark and sludge containing fibres, ash, organic material and micro organisms.

The fly ash and material from the road and mixtures between them were characterized during winter 2008 and spring 2009. A thorough chemical characterization was performed on the ash. Different mixtures (20% and 30% fly ash in combination with road material) were characterized considering optimal water ratio, density and compression strength. The mixtures were also hardened during 6-7 weeks and thereafter characterized considering compression strength and compression strength after 12 freeze-thawing cycles. Soil frost heaving tests were also performed. Based on the results from the laboratory tests and the fact that there was a large supply of ash, it was determined to use a mixture of 30% fly ash and 70% road material in the test sections.

## STABILISATION

### Test sections

The road was stabilised in June 2009. Test sections 1 and 2 were upgraded with mixtures of fly ash and gravel to a content of 30 % fly ash and 70 % road material. Both test sections were covered with 7 cm surface course (gravel size 0-18 mm) (Table 1). No additional binders besides the ash were used in the road.

Table 1. Descriptions of the test sections

	Test section 1	Test section 2
Length (m)	240	260
Fly ash (depth cm)	12	24
Milling depth (cm)	20	39
Depth after compaction (cm)	16	20-25
Surface course (depth cm)	7	7

### Upgradation

Both test sections were upgraded with ditching and grading. The fly ash was transported and laid out by trucks before it was milled into the existing road (Figure 1). The road was thereafter graded again before watering and compaction (6 tons vibration roller, 5 passages). Finally a surface course was laid. The milling was made twice, i.e. back and forth along the sections. The watering of the road became 33 litres per meter. According to the laboratory tests, this amount was sufficient for test section 1 but insufficient for test section 2 with twice as much ash. Damages to the watering machines made it impossible to spread more water.



Figure 1. Milling drum

## FIELD STUDIES

### Homogeneity

In October 2009 altogether 62 samples were taken throughout cross sections of the test sections to estimate the homogeneity in the ash-gravel layer. Samples were taken at two depths below the surface course (5 and 10 cm for test section 1 and 5 and 12 cm for test section 2). The amounts of Zn and Ti were analysed in the samples by XRF (x-ray fluorescence spectroscopy) and the results were related to the element content in pristine ash and gravel.

### Density

The density of the test sections was measured using an isotope meter with direct transmission [11]. Each section was characterized in lengthwise direction and at three cross sections at two depths below the surface course (7,5 and 15 cm for test section 1 and 7,5 and 30 cm for test section 2). The degree of compaction was calculated from the density measurements. The degree of compaction is the measured density related to the density at optimal compaction obtained in the preceding laboratory experiments.

### Bearing capacity

The bearing capacity was measured four times by falling weight deflectometer (FWD) measurements in September 2009, 2010 and May 2010, 2011 [12, 13]. For each loading point the surface modulus has been calculated which indicates the mean stiffness for the whole layer from a certain depth and further below.

## RESULTS AND DISCUSSION

### Laboratory studies

The laboratory studies showed that the compression strength was enhanced with increased amount of ash in the samples. The pozzolanic properties further enhanced the compression strength after accelerated hardening (carbonation) and the mixture of 30 % ash and 70 % gravel had a compression strength of 9,7 MPa (Figure 2). After 12 cycles of freeze-thawing, the compression strength was reduced for the mixture with 20 % ash (from 6,7 MPa to 5,6 MPa) but for the mixture with 30 % ash the compression strength was enhanced (from 9,7 MPa to 13,9 MPa) (Figure 2). The possible explanation is that hardening of the samples with 30 % of ash was still continuing after the first measurement. The samples were not influenced by the soil frost heaving experiments.

When upgrading a road in Iggesund [7] their mixture containing gravel/fly ash/green liquor/cement in proportions 80%/16%/3,6%/0,4% obtained an initial compression strength in laboratory experiments of 0,4 MPa and the compression strength increased to 1,4 MPa after 90 days of hardening. In Hallstavik [6] a road was stabilised with 30% fly ash. In the preceding laboratory experiments, the ash/gravel mixture (30%/70%) obtained a compression strength of 2,2 MPa after 28 days of hardening and the compression strength was lowered to 1,3 MPa after freeze-thawing experiments. The relatively high compression strength obtained for the fly ash used in Sörkrånge (9,7 MPa after hardening) thus determined that this stabilisation was performed without using any other additives. [14]

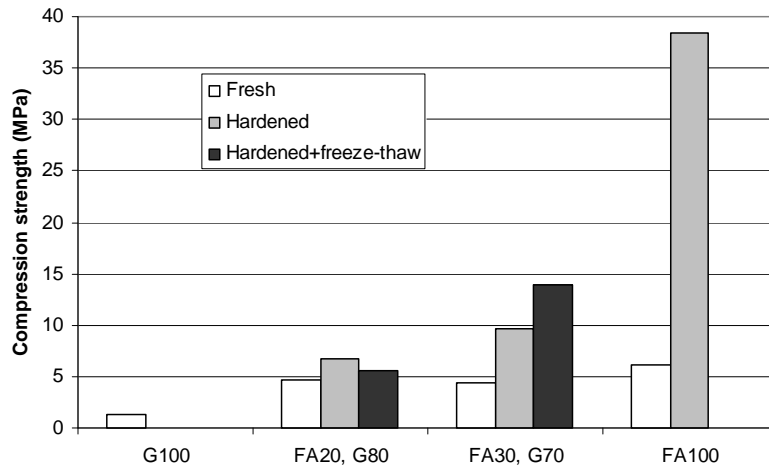


Figure 2. Compression strength for untreated samples (white), carbonated samples (grey) and carbonated samples exposed to 12 freeze-thaw cycles (black). FA100 denotes 100 % fly ash, FA20G80 denotes 20 % fly ash and 80 % gravel, FA30G70 denotes 30 % fly ash and 70 % gravel, G100 denotes 100 % gravel.

### Homogeneity

Analyses of the ash content showed that the ash was unevenly distributed across the road and the average content varied between 22 and 36 % (Table 2, Figure 3). The target content was 30 %. The ash content showed larger variations between different depths than in the lengthwise or transverse directions. This may indicate that the mixing of ash into the road was insufficient at deeper levels. The distribution of ash was more uneven in test section 1 than test section 2 (Figure 3). Data of homogeneity is lacking from other roads stabilised with fly ash. To evaluate and improve the construction methods it would be interesting to compare different roads and relate the results to the bearing capacity.

Table 2. Ash content (%) as mean  $\pm$  standard deviation in test section 1 (n=31) and test section 2 (n=31)

Depth below surface course	Test section 1	Test section 2
5 cm	35 $\pm$ 21	27 $\pm$ 7
10-12 cm	35 $\pm$ 28	24 $\pm$ 13

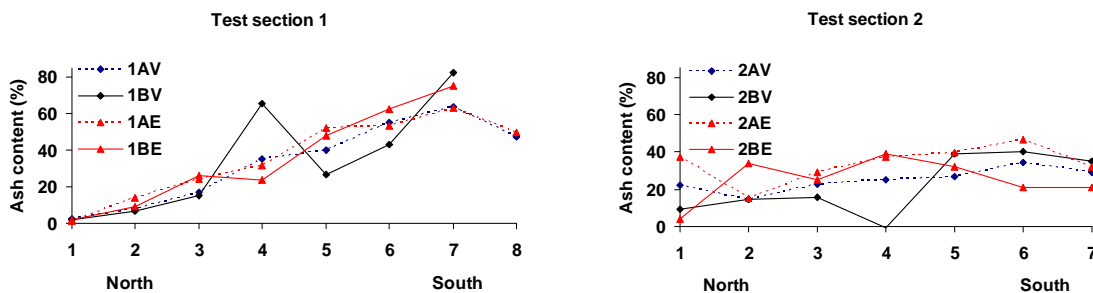


Figure 3. Ash content in road samples from cross section from test sections 1 and 2, western (V) and eastern (E) shaft wall. A-samples were taken at a depth of 5 cm below surface course. B-samples were taken at a depth of 10 cm below surface course in test section 1 and 12 cm below surface course in test section 2.

### Density

The density in field was in most cases lower than the optimal density obtained from the preceding laboratory tests and mostly the density increased with depth. The density was similar both in

transverse and lengthwise directions and there was no distinct difference in density across the road which may reflect the low traffic load. The higher density and thereby the higher degree of compaction at deeper levels indicates that the milling of the ash did not reach the desired depths and that the road material thus has not been loosened at these depths. To obtain good properties for the road, the degree of compaction should be at least 92% and the water ratio in the mixture is pointed out as an important factor to obtain a high degree of compaction [14]. Only a few of the shallower points in the investigated road achieved that degree of compaction (92%). In the preceding laboratory studies, the optimal water ratio of the ash gravel mixture was 25%. During upgrading, the water ratio in the road was measured to 13-15%. The low water content probably in combination with insufficient compaction is likely to be the reason for the low degree of compaction in the road.

Table 3. Degree of compaction (%) for the two test section in transverse directions as mean  $\pm$  standard deviation.  $n=3$  for each section, depth in cm

	Depth	Left road side	Left track	Centre	Right track	Right road side
Test section 1	7,5	69 $\pm$ 7	85 $\pm$ 4	82 $\pm$ 4	91 $\pm$ 11	97 $\pm$ 20
	15	77 $\pm$ 3	89 $\pm$ 6	91 $\pm$ 5	100 $\pm$ 12	108 $\pm$ 20
Test section 2	7,5	80 $\pm$ 10	83 $\pm$ 8	83 $\pm$ 14	81 $\pm$ 10	84 $\pm$ 2
	30	98 $\pm$ 16	97 $\pm$ 2	99 $\pm$ 9	103 $\pm$ 5	104 $\pm$ 6

Table 4. Degree of compaction (%) for the two sections in lengthwise direction as mean  $\pm$  standard deviation.  $n=6$  for test section 1 and  $n=7$  for test section 2, depth in cm

Depth	Test section 1	Test section 2
7,5	82 $\pm$ 8	83 $\pm$ 13
15	87 $\pm$ 5	
30		102 $\pm$ 13

### Bearing capacity

The bearing capacity was measured four times (September 2009, 2010 and May 2010, 2011). In general, the stiffness was lower in spring than in autumn due to the higher water content in the road during this measurement, but the stiffness of test section 2, with twice as much ash, was not reduced as much during spring measurements as the stiffness of test section 1 (Figure 4). The stiffness of both test sections increased with time and the stiffness of test section 2 had a better development than the stiffness of test section 1.

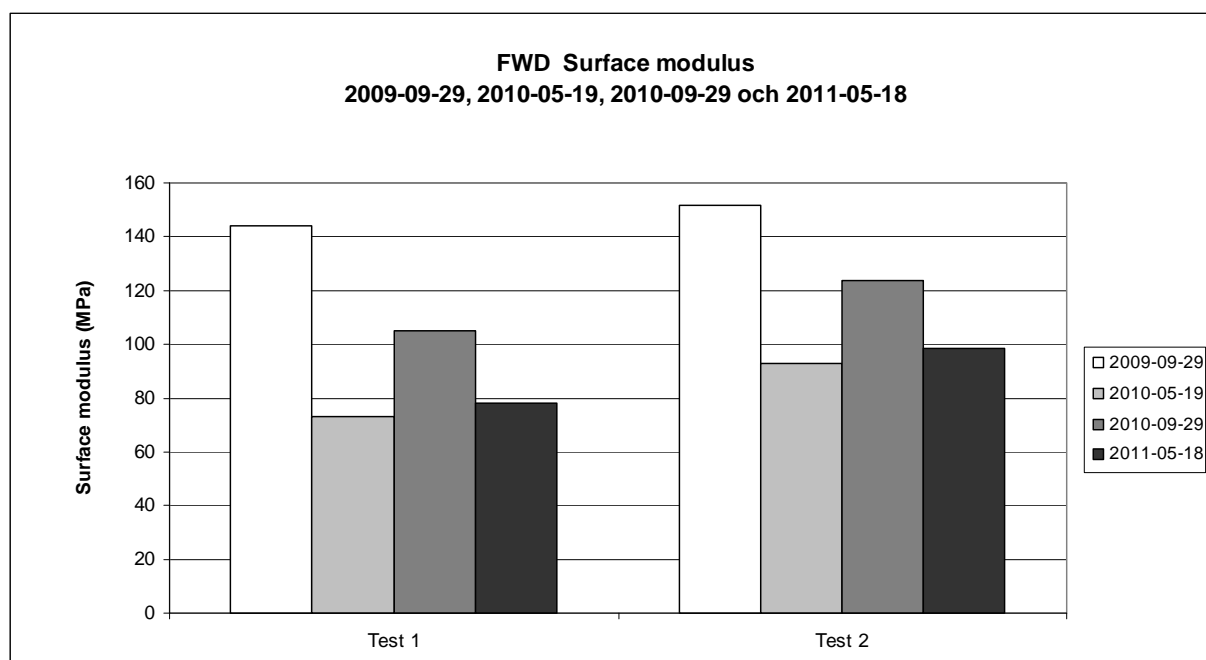


Figure 4. Surface modulus for the test sections measured at four different occasions (Sept. 2009, 2010 and May 2010, 2011).

## CONCLUSIONS

Laboratory and field studies showed that this fly ash was suitable for stabilising gravel roads without using any other additives. The homogeneity of the ash-gravel layer varied, although the expected 30 % mixture of ash was obtained in average. The obtained degree of compaction was in general too low probably due to low amount of water and insufficient compaction after mixing. Test section 2, with twice as much ash as in test section 1, had a better stiffness development according to the falling weight deflectometer measurements.

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