Transportation Geotechnics 14 (2018) 146–156

Contents lists available at ScienceDirect

Transportation Geotechnics

journal homepage: www.elsevier.com/locate/trgeo

Biofuel ash in road stabilization – Lessons learned from six years of field testing

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ARTICLE INFO

Article history:
Received 29 September 2017
Revised 16 December 2017
Accepted 17 December 2017
Available online 19 December 2017

Keywords:
Fly ash
Recycling
Stabilization
Leaching
Infiltration, bearing capacity

ABSTRACT

In 2009, pulp mill fly ash was used for stabilizing the road base of a low-volume gravel road. Six years after stabilization, a two-year monitoring program and a complementary study were conducted to study the environmental and technical properties of the road and road material. Environmental properties were studied through chemical analysis of road samples by X-ray diffraction (XRF), inductively coupled plasma (ICP) technique and colorimetric techniques. The strength development was studied by falling weight deflectometer (FWD) and compressive strength tests. Potassium (K) and sulphate sulfur (SO_4-S) concentrations in road material decreased by 40 and 55%, respectively during this time. Absolute concentrations of most trace elements increased. Leaching of chloride (Cl) salts from road samples decreased with time, while leaching of magnesium (Mg) and calcium (Ca) increased. Leaching of trace elements was below 0.5 mg/kg at all sampling occasions. The bearing capacity increased by 30–50%, and the infiltration capacity decreased compared to a reference section. The results showed that the ash-stabilized sections performed better than conventionally upgraded sections and achieved increased bearing capacity over time. Since the acid neutralizing capacity of the stabilized layer was high and lumps of unreacted ash were still left in the road, it was concluded that the ash material could be utilized once more in a potential end-of-life road recycling.

Introduction

Open gravel roads are sensitive to water accumulation, which may reduce their stability and bearing capacity. The present climate trend in mid Sweden, with increased average annual temperatures and rainfalls, will lead to shorter frost periods, increased soil moisture and thus decreased bearing capacity. Since the forestry is dependent on accessible roads throughout the year, stabilizing forest roads is of growing concern. To increase the bearing capacity of the road, binders like fly ash can be used [10,27]. Fly ash contains mainly calcium and silicate oxides and has thus pozzolanic properties which results in high compression strength and bearing capacity [14,26,28,31,17,24,18]. The unique properties of the ash, and thus the stabilizing capacity, depend on the fuel and the type of incineration plant. The pozzolanic properties of the ash may be further enhanced by additives like cement or calcium oxide but the use of additives increases the costs, both during construction and when the road must be rebuilt. However, there is little documentation of how these ash-stabilized roads will perform in a longer perspective and there is thus a need for long-term studies [13].

In 2009, the Swedish Forest Agency together with the Swedish Geotechnical Institute and Luleå University of Technology initiated a project in which a low-volume gravel road was upgraded and stabilized using fly ash from a local paper mill. No other additives were added. The Swedish environmental protection agency has developed guideline values (total concentration and leaching limit values for pollutants) for recycling of waste in constructions [19]. If the values are not override, the waste can be used in constructions; otherwise the user must seek for permission by the authority at the County Administrative Board. During the first two years, the technical and environmental properties of the road were monitored. The laboratory tests preceding the upgrading and the environmental impact from the road are discussed in Nordmark et al. [15]. Evaluation of the construction method and the technical perfor-

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https://doi.org/10.1016/j.trgeo.2017.12.002
2214-3912/

mance of the road are discussed in Arm et al. [1]. In summary, the results showed that the test sections with fly ash had an initial leakage of K, Na, Cl and SO_4, but after two years the leakage was similar in the test and reference sections. Furthermore, the test sections had higher stiffness, especially during frost thawing periods which are critical to transports during spring time.

Since long-term studies mostly are lacking, it is interesting to follow the performance of ash-stabilized roads several years after upgrading. This paper describes the technical and environmental properties of the ash-stabilized road, six years after upgrading (in 2014–2015). The paper also aims to perform a long-term forecast for the technical and environmental properties of the road and to discuss how to handle the ash-stabilized material when the road has reached end-of-life. Would it be possible to reuse and/or reactivate the material or would the material be considered as waste? When possible, the results of this complementary study were compared with the results of the previous studies [1,15].

Materials and methods

Pavements, stabilization and ash material

The upgraded road is situated in Timrå municipality, in the middle of Sweden (62°30′N 17°20′E). It is a primary forest road, around 1.5 km in length and divided into two test sections and four reference sections (Table 1). All sections have been exposed to ditching and grading. Two reference sections were left without further upgrading and two reference sections were upgraded with a new base and a new surface course (Table 1, Fig. 1). In the test sections, ash was milled into the road to a mix with 30% of fly ash and 70% of road base material (diamicton – glacial till) (Table 1). After milling the ash into the existing road and thereafter watering and compaction, a new surface course was laid on the test sections and on the two reference sections with new base courses. For detailed information about the stabilization method see Arm et al. [1]. Fig. 2 shows some of the sections during snow melting period 2015.

The fly ash used for stabilization was produced at the paper mill Ortviken located in Sundsvall in mid Sweden, where bark and sludge containing fibres, ash, organic material and microorganisms are burnt in a fluidized bed incinerator at 730 °C. The yearly production of fly ash at this paper mill is around 10,000 tonnes which mostly is used as landfilling material. Measured as oxides, it contained 41% of Si, Al and Fe oxides and 36% of CaO, and was classified as a Class C fly ash according to ASTM C618 [2]. The CaO content of Class C ashes is usually over 20%, which results in cementitious properties. The CaO/SiO_2 ratio was 1.53, which is above 1.5 and indicates according to Röhling et al. [16] no need for an activator, e.g. cement, to cure. In Table 2 are selected properties of Ortviken fly ash and typical puzzolans presented.

The carbonation potential of the ash was assessed by treating the ash with CO_2 at 100% relative humidity and 30 °C until equilibrium was reached. The carbonation potential was measured by the increase in total (TC) and inorganic carbon (IC) concentration in the ash [4]. The content of IC increased from 0.6% to 4% during the treatment, which corresponds to an uptake of about 135 kg CO_2 per tonne of ash. The increase is due to the deposition of carbonates in the pore water that occurs when CO_2 dissolves in the pore water in alkaline environment and then reacts with dissolved cations, such as Ca^{2+}. The precipitation of carbonates contributes to the ashes stabilization along with puzzolanic reactions.

Inorganic element composition and leaching data of the fly ash and road material is given in Tables 3 and 4 together with guideline values for recycling of waste in constructions [19]. For detailed information about the ash and gravel properties such as leaching data and grain size distribution, see Nordmark et al. [15].

Sampling and analyses of ash/till layer

In 2014, samples of the ash stabilized layer were collected at two depths below the surface course in test section 2, at 0–5 cm and at 5–10 cm and with 4 m between the sampling points. Altogether, 18 samples of about 0.5 kg each were taken. Besides, three samples were collected in reference section 2 at 0–5 cm depth below the surface course. Preparation of the samples before analysis followed the same procedure as in the previous study and is described in Nordmark et al. [15]. Analytical methods are presented in Table 5. The results were evaluated and compared with results of samples collected in October 2009, May 2010 and June 2011.

Road surface infiltration capacity

Infiltration capacity of the road surface in test section 2 and reference section 2 was measured using double-ring infiltrometers. The measurements were made in the road centre (four replicates) and in the wheel tracks (four replicates). The surface course (about 70 mm) was removed before measuring. During the measurements, the water level in the inner ring was held constant and the volume of water that was added to maintain a constant level was measured. When the infiltration rate had been constant for about one hour the measurements were stopped. The measurements were performed in June 2015 and the results were compared with results of measurements in June 2011.

Table 1
Description of test sections and reference sections [1].

	Section length (m)	Upgrading material	Fly ash thickness[a] (cm)	Milling depth[b] (cm)	Stabilized base course thickness[c] (cm)	New base course thickness[d] (cm)	Surface course thickness[e] (cm)
Test 1	240	Fly ash	12	20	16	–	7
Test 2	260	Fly ash	24	39	20–25	–	7
Ref 0	400	None	–	–	–	–	–
Ref 1	320	Gravel	–	–	–	15	7
Ref 2	160	Gravel	–	–	–	15	7
Ref 3	120	None	–	–	–	–	–

[a] After spreading.
[b] From surface of ash layer.
[c] After milling and compaction.
[d] Crushed gravel with grain size 0–32 mm.
[e] Crushed gravel with grain size 0–18 mm.