Original scientific paper

Untreated Wood Ash as a Structural Stabilizing Material in Forest Roads

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Abstract

Due to the euphoric use of »green« energy produced by biomass power plants, up to 350 000 tons of ash are accumulated as a waste product every year in Austria and the estimated costs for landfilling are 1.7 million € per year. For this reason, methods must be found for the utilization of wood ash. One solution is to use it as a stabilizing material in forest roads. The pozzolanic characteristic of ash is used to bind the gravel in the road base. Wood ash is expected to reduce the need for gravel on forest roads and at the same time to enhance the load bearing capacity of forest roads.

Two different untreated wood ashes were used in two mixture ratios, each on a 50 meter long forest road section, to investigate the load bearing capacity. The ashes were selected by their different properties: high lime and low heavy metal content, production of ashes in Austrian biomass power plants with various furnace technologies and disposal costs. Mixing depth was 0.50 m and the road base was covered by a 0.10 m thick surface layer. Elastic moduli of these sections were measured before the application, and repeated monthly by using a light falling weight deflectometer.

After the first vegetation period, the mean elastic modulus of the sections mixed with dry bed ash showed an improvement. The increase of the initial mean load bearing capacity of 32.0 MNm^{-2} was 65% for 15/85 mixture and 76% for 30/70 mixture. The results for the fluidized bed ash sections fell short of expectations. Only 95% of the initial value could be reached for both mixing values.

Keywords: wood ash, utilization, forest road, load bearing capacity, stabilization

1. Introduction

The energy generated by biomass has gained importance in recent years. It is an essential contribution to sustainable regional energy supply, especially in Austrian wooded areas. Wood ash, produced in these processes, was previously considered to be a »waste-product« (Stupaka et al. 2007). In the late 1990s the Austrian Advisory Board for Soil Fertility highlighted the properties of this secondary raw material. Recycling of minerals corresponds to the ecological principle of the closed biogeochemical cycles and helps to spare natural mineral resources (Holzner and Obernberger 2011).

In the year 2007, the total ash production of biomass use in Austria was 350 000 tons; 295 000 tons in biomass power plants and 55 000 tons in small scale burning facilities, where further use is unknown. 125 000 tons were recycled and the rest of 170 000 tons was landfilled (Environment Agency Austria 2009). With an average fee of 100 € per ton of deposited material, the total costs for the annual ash disposal is 1.7 million € just for landfilling. It is necessary to develop methods of wood ash utilization so as to prevent this nutrient rich material from being landfilled. Depending on the characteristics of different types of wood ash, various purposes can be selected. Recycling nutrients of wood ash by using it as fertilizer has been common for a very long time (Holzner 1999). Another method could be the reinforcement of unpaved low-volume forest roads (Lahtinen 2001).

In Austria, the standard of the secondary road network is very high. Almost all roads in this network are paved. Low-volume roads are mostly situated on agricultural or forested areas and mainly used by the land owners. In other European countries public use of low-volume roads is more frequent and their legal frameworks allow the use of alternative structural road materials like wood ashes. Due to mismanagement of ashes in large road constructions and introduction of stricter regulations, there had been some setbacks in the establishment of ash as binding material (Kärrman et al. 2004). However, results of research on ecological influence (Lahtinen 2001, Thurdin 2004), and technical requirements and quality criteria of wood ash (von Bahr et al. 2006) formed the basis for suitable guidelines of ash application (Munde et al. 2006).

The main objective was to verify the suitability of untreated wood ash as a reinforcing structure material in the load bearing layer of low-volume roads based on the hypotheses that wood ash is self-hardening. Unlike the experiments in Scandinavia with pure fly ashes or in combination with other industrial by-products (Lahtinen 2001, Mácsik and Svedberg 2006), where the influence of the mixture properties is managed by changing the proportion of different components, in this study untreated dry bottom ash and fluidized bed ash were used. In the case of suitability, gravel could be replaced with wood ash resulting in a cost-effective use of wood ash in forest road construction.

2. Material and Methods

2.1 Road reconstruction

The initial situation was an existing forest road in need of maintenance and reconstruction in some places. The geographical position of the research area was the Attergau (47° 56′ N, 13° 88′ E), where most of the parental material contains flysch. Flysch is a combination of clay, argillite, lime rock and sandstone. Under dry conditions, the subgrade has a high load bearing capacity, but with increasing moisture it loses strength. So the superstructure of a forest road in flysch areas has to provide a stable layer. In most cases this aim is reached by constructing a bulky bearing layer of compressible gravel.

For an average subgrade elastic-modulus of 20 MNm^{-2}, it is possible to reach 30 – 35 MNm^{-2} under dry conditions and with compaction. Based on this, a road surface elastic modulus of 80 MNm^{-2} with a 0.20 – 0.30 m thick load bearing layer made of gravel with a grain size distribution curve of 0 – 60 mm can be reached (Dietz et al. 1984). With a flysch subgrade, the elastic modulus often drops below 10 MNm^{-2}. For this reason, 0.40 – 0.50 m gravel is used to construct the load bearing layer to reach the necessary load bearing capacity. This structural element is covered by a surface layer of gravel with a grain size distribution curve of 0 – 32 mm.

During the reconstruction of a forest road of a total length of 1 850 m, four 50 m sections (Fig. 1) were reinforced with two different types of wood ash, dry bottom ash (DBA) and fluidized bed ash (FBA) in two mixing ratios (15% ash to 85% original forest road material and 30% ash to 70% original forest road material). On a fifth section, the forest road received the same treatment without wood ash, which served as a control treatment, and a sixth section remained untreated to provide reference data of load bearing capacities. The elastic modulus was measured on these sections, and the data were compared. In the text below, these sections will be referred to as:

- DBA–X for dry bottom ash, where X is the percentage of dry bottom ash mixed with original material, for example DBA-30 for 30% dry bottom ash to 70% original material;
- FBA–X for fluidized bed ash, where X is the percentage of fluidized bed ash mixed with original material;
- TWOA for treatment without ash (mixing, rolling and grading);
- REF for reference with no treatment.

The mixing ratios are related to the application of other binding materials like lime or Portland cement (Dietz et al. 1984). The effectiveness of the reinforcement are, on one side, dependent on the ash characteristics, which are influenced by the type of combustion, differing fuel types structure of grains and free lime content. On the other side, the main factors for a good performing load bearing layer are heterogeneous base material and the optimal water content. Earlier research showed that a small addition of lime caused a significant improvement of strength (Lahtinen 2001).

2.2 Bearing layer construction

Depending on the mixing ratio, a 0.08 m (15/85) or 0.12 m (30/70) thick layer of wood ash was applied onto the road surface. After that the mixing procedure was done by a WR 2400 recycler, a product of the Wirtgen Company, with a mixing depth of 0.50 m and a working width of 2.40 m (Fig. 2 and Fig. 3). The machine hydraulic system guaranties a homogenous mixing result by keeping the rotation speed of the mill constant and varying the machine speed. Under dry soil conditions, an additional water tank supplies the recycler with water to reach the required moisture and prevents dust formation. After the mixing procedure, the modified load bearing layer is covered by a 0.10 m thick surface layer of gravel with a par-

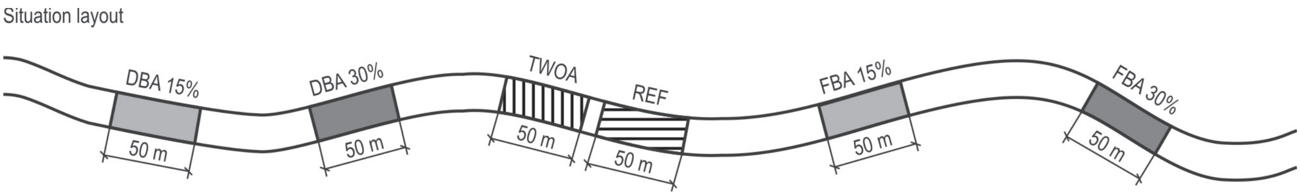

Fig. 1 Layout overview

Fig. 2 WR2400 recycler during mixing process

ticle size of 0 – 32 mm. The finalizing treatment included conventional grading and compacting with a vibrating roller.

2.3 Falling weight deflectometer

The load bearing capacity was measured with a falling weight deflectometer (FWD). It was originally used to evaluate the physical properties of pavements like the in situ base and subgrade moduli during construction. FWD data allows to estimate the pavement structural capacity for overlay design and to determine if a pavement is being overloaded.

In this test, a Light Falling Weight Deflectometer TerraTest 3000 GPS from the TerraTest Company was used (Fig. 4 and Fig. 5). The big advantage, in comparison to other measuring methods, is the fast and easy repetition of measurements on different sample plots (Tholen et al. 1985).

The measurement is based on the impulse of the light falling weight, which drops the loading plate with a diameter of 0.30 m. This impulse generates a maximum force (F_{max}) of 7.07 MN. This force is gauged

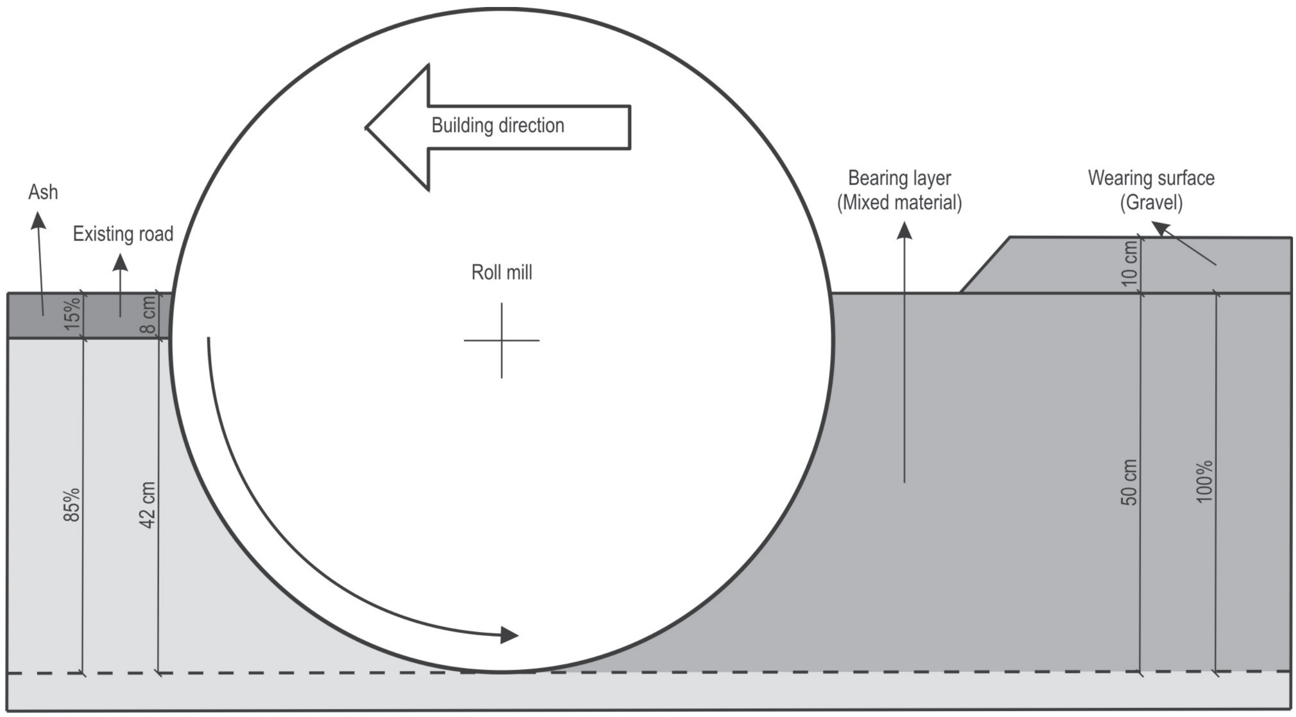

Fig. 3 Scheme of the reconstruction procedure

Table 1 Elastic modulus of all sectio

	DBA–30		DBA–15		FBA–15		FBA–30		TWOA		REF	
Date	*mean*	*N*	*mean*	*N*	*mean*	*N*	*mean*	*N*	*mean*	*N*	*mean*	*N*
06.05.2010	19.996	39	*29.934*	12	*18.220*	27	*16.653*	36	21.256	6	*36.554*	24
12.05.2010	*18.481*	36	30.161	18	22.076	30	21.371	33	19.506	6	44.569	24
27.05.2010	22.392	33	31.701	27	22.167	30	17.897	33	*13.027*	6	44.619	24
23.06.2010	31.740	42	39.931	27	25.758	33	19.696	36	21.466	6	42.924	24
22.07.2010	51.373	36	42.607	24	**41.996**	33	**36.162**	33	**41.190**	6	**62.766**	24
23.08.2010	47.853	27	53.294	15	28.276	24	19.696	36	39.327	6	50.216	24
22.09.2010	**56.360**	48	**52.937**	27	30.300	39	30.241	48	32.049	6	49.666	24
04.11.2010	55.817	36	52.821	24	31.858	33	28.500	36	28.817	6	50.133	24

during the calibration to ensure a normal tension of 0.1 MNm^{-2} under the plate while performing the tests. Deflection sensors mounted on the load plate measure the deformation of the pavement in response to the load. The deformability parameter of the soil caused by this impulse is the elastic modulus called E_{vd} and is calculated by the Light Falling Weight Deflectometer TerraTest 3000 (TERRATEST 2009).

$$E_{\mathrm{vd}} = 1.5\, r \frac{\sigma_{\max}}{s_{\max}} \qquad (1)$$

Where:

s_{max} mean value of the displacements σ_{4max}, σ_{5max}, σ_{6max} of 3 measurements after 3 preconsolidation measurements, m;

r radius of the plate, m;

σ_{max} normal tension under the plate, MNm^{-2}.

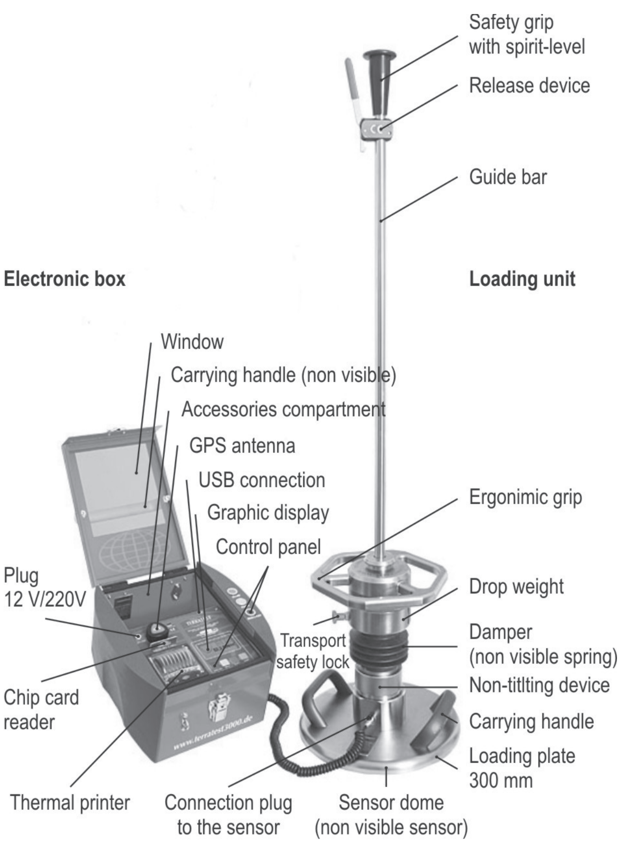

Fig. 4 Falling weight deflectometer TerraTest 3000

Fig. 5 TerraTest 3000 in use

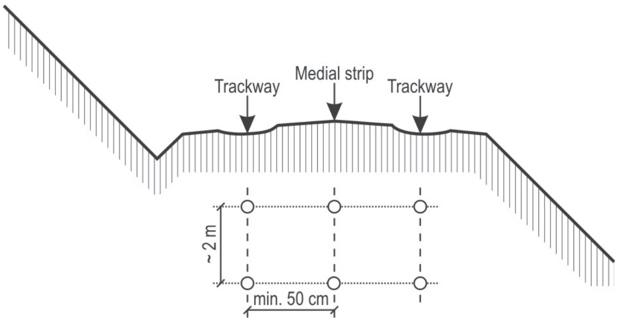

Fig. 6 Layout of elastic-modulus measurement depending on the surface location

The measurements were taken on the trackway and on the medial strip of the road (Fig. 6). The reason for this layout was to find different measurement parameters for the influence of the upcoming traffic. While the whole load of the upcoming traffic was an additional compacting force on the trackways, the medial strip stayed untreated after the road construction was completed.

2.4 Traffic observation and load calculation

For the calculation of the bearing load [t], the traffic was observed during the whole growing season from 6th May to 11th November 2010 (Fig. 7) with scouting cameras, which have an integrated motion detector combined with an automatic release. Pictures were taken of every type of moving vehicle, truck with or without trailer, agricultural tractor or car on the forest road. For the load detection, a second camera was mounted facing the opposite direction. The pictures from the backside of the trucks were used to estimate their load. These estimations were based on sample loads recorded on delivery notes of the saw mill and summed up daily. A total of 3 570 tons was transported on the road during the observation.

2.5 Basic meteorological data

The climate in the research area around Weyregg am Attersee is warm and temperate. There is significant rainfall throughout the year, even in the driest month (81 mm). The region is described as Cfb in the Köppen-Geiger climate classification system. The average annual temperature is 8.2 °C and the precipitation approximately 1 318 mm per year (Fig. 8).

3. Results and discussion

In total 1 251 elastic modulus measurements were taken on eight different days. The total elastic modulus ranged from 5.70 – 114.20 MNm^{-2} (Table 1). The mean elastic modulus of the whole forest road was measured before any treatment and had a mean value of 32.0 MNm^{-2}. The elastic modulus of the treated sections was reduced by the disaggregation of the mixing process. It took approximately three months for each section to reach the initial value of the forest road again. The mean elastic-modulus of the reference section varied in the observed time between 36.55 and 62.78 MNm^{-2} and at the end it was 50.13 MNm^{-2}.

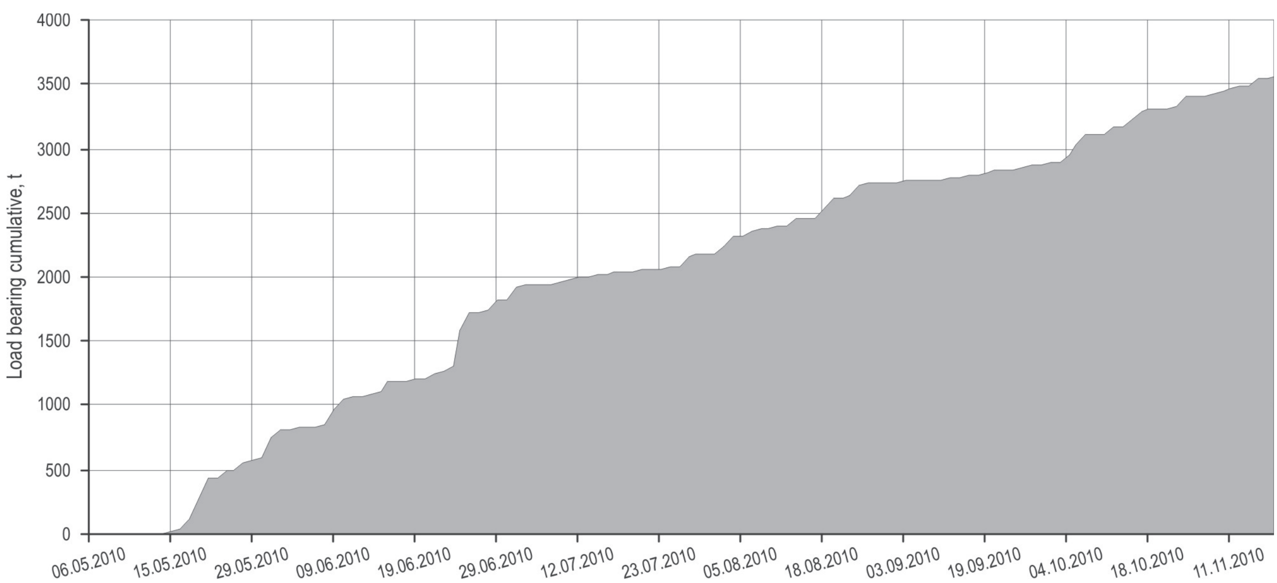

Fig.7 Loads of the upcoming traffic

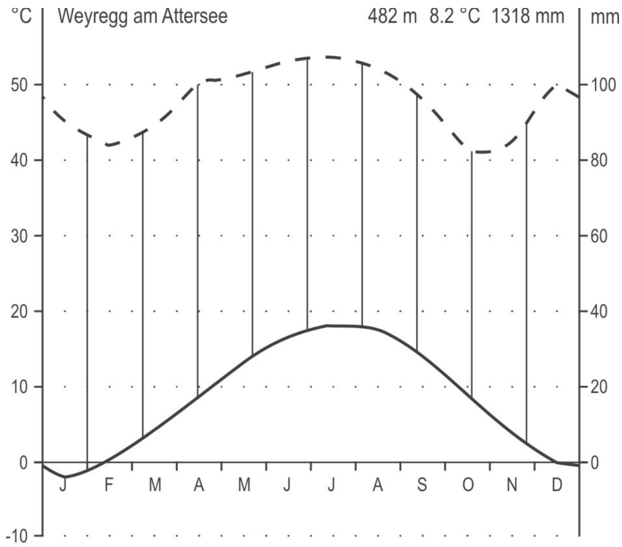

Fig. 8 Climograph

In the case of a total reconstruction, comparison with the initial situation is not possible, because the whole road needs stabilizing or conditioning to make sure that the road can be used for traffic. With the DBA, it is possible to increase the elastic modulus by more than 20 MNm^{-2}, compared to mechanical stabilization. FBA was not suitable for reinforcing the road construction, neither 15 % nor 30 % (Fig. 10). The two reasons for this behaviour are the different content of free lime in both ash types and the grain structure and size (von Bahr et al. 2004).

The difference between the influence of the mixing values and ash types was checked with ANOVA and the Duncan Test. The results of 5th May confirmed no significant difference of the elastic modulus between FBA-30, FBA-15, DBA-30 and TWOA. DBA-15 and REF exhibited a significantly higher elastic-modulus (Table 2). The observation on 4th November 2010 shows no significant difference between both FBA sections and the TWOA section. The DBA sections showed no significant difference from the REF section (Table 3).

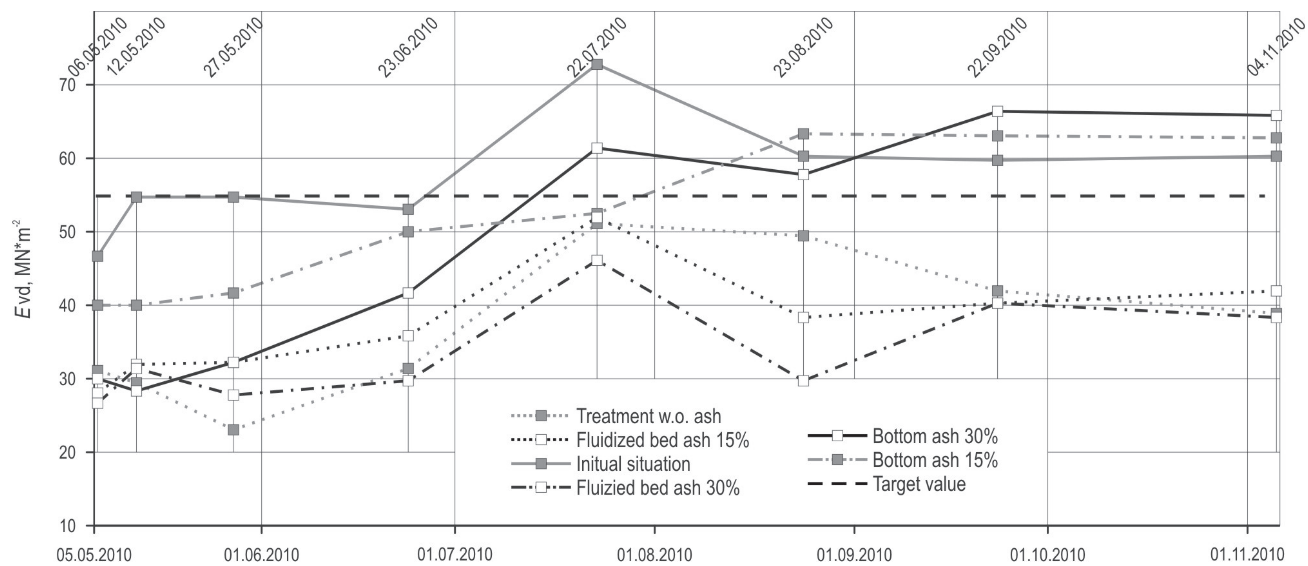

Fig.9 Development of elastic moduli of all sections over growing season

Over the 6-month period, the sections treated with dry bottom ash increased their elastic moduli significantly. An improvement of the elastic modulus of 5.4% (52.8 MNm^{-2}) for the DBA–15 section and 11.3% (55.8 MNm^{-2}) for the DBA–30 section was detected.

The results for the fluidized bed ash sections fell short of expectations. Only 31.9 MNm^{-2} for the FBA–15 section and 28.5 MNm^{-2} for the FBA–30 section could be reached for both mixing values. This was nearly 95% of the initial value and 63.5% (FBA–15) and 56.8% (FBA–30) of the reference value (Fig. 9).

The hypothesis that forest roads can be reinforced by the application of wood ash could be confirmed for DBA with the mixing values of 15/85 and 30/70, but disproved for FBA with a similar mixing value. After one growing season the elastic-modulus of the DBA sections had surpassed the values of the REF section.

The influence of the traffic did not show the expected results. The hypothesis that the additional com-

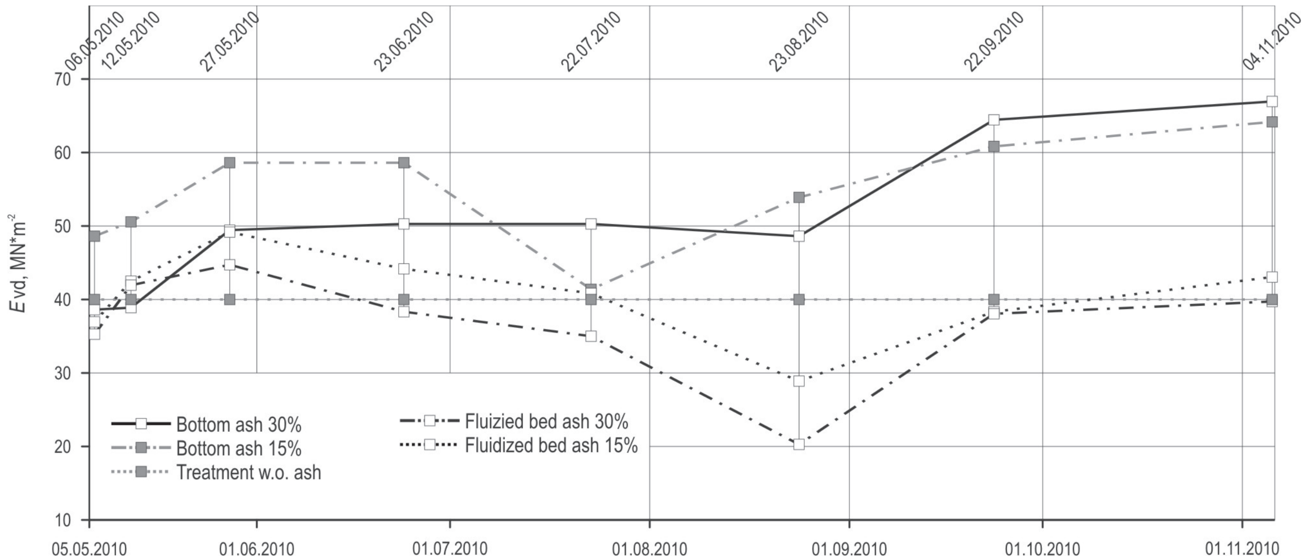

Fig. 10 Comparison of elastic moduli of sections treated with and without ash

Table 2 ANOVA (Duncan Test) for results of 6 May 201

Section	*N*	Subcategory for Alpha = 0.05.		
		1	2	3
FBA–30	36	16.65	–	–
FBA–15	27	18.22	–	–
DBA–30	39	20.00	–	–
TWOA	6	21.26	–	–
DBA–15	12	–	29.93	–
REF	24	–	–	36.55
Significance		0.19	1.00	1.00

Table 3 ANOVA (Duncan Test) for results of 4 November 2010

Section	*N*	Subcategory for Alpha = 0.05.	
		1	2
FBA–30	36	28.50	–
TWOA	6	28.82	–
FBA–15	33	31.86	–
REF	24	–	50.13
DBA–15	24	–	52.82
DBA–30	36	–	55.82
Significance	–	0.46	0.20

paction due to traffic leads to higher elastic moduli on the trackways could not be verified. The mean elastic modulus (Mean), elastic modulus of the trackway (Track) and medial strip (Middle) of three different sections were measured and compared.

On 23th of August 2010 the measurements on the bottom ash section showed higher elastic modulus at the medial strip than at the trackways. The same effect was measured on 26th of June and 22th of September for the section treated without ash (Fig. 11).

The reference measurements show (Fig. 9) a variation over the whole growing season, which could be caused by the influence of weather conditions. For subsequent measurements, meteorological stations will provide exact weather data for closer consideration.

To reach the target elastic modulus of 45 MNm^{-2}, the self-hardening process of wood ash, initiated by water contact, is important. The dryness of the used ashes must be guaranteed via logistical organization. The ash is transported directly from the power plant to the construction site, where the ash is mixed with the raw material. It starts hardening by water contact and it is sealed with the surface layer. Outdoor storage and the contact with air humidity will definitely influence the self-hardening process of ashes and should be prevented. If there is no possibility of subsequent treatment, the ashes have to be covered with water proof material (von Bahr et al. 2004). The limiting factor in forest road construction will be the cost in money. Long term observations will show the potential of the cost effectiveness of this reinforcing method.

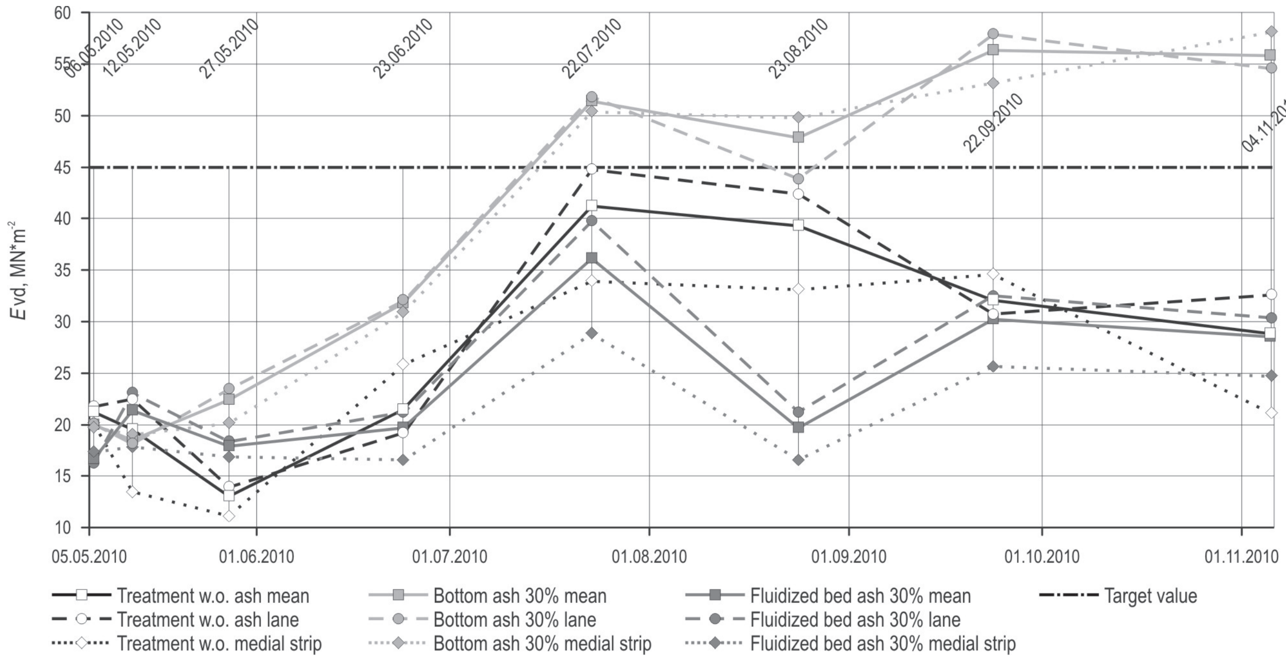

Fig. 11 Mean elastic moduli depending on the surface location

4. Summary

For the evaluation of untreated wood ash as a structural stabilizing material, two different ash types were applied in two mixture ratios, each on a 50 meter long forest road section, to investigate the load bearing capacity. The ashes were selected by their different properties: high lime and low heavy metal content, their production in Austrian biomass power plants with various furnace technologies and disposal costs. The mixing depth was 0.50 m and the road base was covered by a 0.10 m thick surface layer. The elastic moduli of these sections were measured before the application, and repeated monthly by using a light falling weight deflectometer.

After the first vegetation period, the mean elastic modulus of the sections mixed with dry bed ash showed an improvement. The increase of the initial mean load bearing capacity of 32.0 MNm^{-2} was 65% (52.821 MNm^{-2}) for 15/85 mixture and 76% (55.817 MNm^{-2}) for 30/70 mixture. The results for the fluidized bed ash sections fell short of expectations. Only 99% (31.858 MNm^{-2}) for the 15/85 mixture and 89% (28.500 MNm^{-2}) for the 30/70 mixture of the initial value could be reached.

The results of the field trial show that dry bed ash is suitable as a structural stabilizing material. This could not be confirmed for the fluidized bed ash. In this case other utilization methods should be exploited.

5. Literature

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