Usage of Wood Fly Ash in Stabilization of Unbound Pavement Layers and Soils

Pēteris Šķēls¹, Kaspars Bondars², Raitis Plonis³, Viktors Haritonovs⁴, Andris Paeglītis⁵

^{1,2}*Department of Civil Engineering, Technical University of Riga, Riga, Latvia*

^{3,4,5}*Department of Roads and Bridges, Technical University of Riga, Riga, Latvia*

E-mails: ¹peteris.skels_1@rtu.lv (corresponding author); ²kaspars.bondars@rtu.lv; ³raitis.plonis@rtu.lv; ⁴viktors.haritonovs@rtu.lv; ⁵andris.paeglitis@rtu.lv

Abstract. Modification and stabilization of road structure unbound layers has extensively been studied both at laboratory and field for decades. The most commonly used binders for soil modification and stabilization are cement and quicklime (CaO), but alternative pozzolans and their mixtures are of economical, technical and environmental interest. This study presents soil stabilization with wood fly ash (WFA) at laboratory. Natural sand (Sa), Sa mixtures with 10% and 20% WFA were compacted at optimal water content according to Standard Proctor test LVS EN 13286-2:2012, and California bearing ratio (CBR) tested according to LVS EN 13286-47:2012 for cured samples after 96 hours immersed in water with 2 kg surcharge and after 7 days sealed simultaneously. At the same time also Immediate bearing index was determined for natural soil and their mixture with 10% WFA. Results showed 3.79 times enhancement in CBR values Sa after 7 days curing, justifying that WFA is valuable material for hydraulically bound mixtures.

Keywords: soil stabilization, wood fly ash (WFA), hydraulically bound mixtures.

Conference topic: Soil and rock investigation.

Introduction

European Parliament and Council Directive 2009/28/EC (on the promotion of the use of energy from renewable sources) states that the renewable energy sources (RES) share (gross final energy consumption) in 2020 should be 40%. The future estimations in Latvia illustrates that 2.42 milj. tons of firewood (mostly wood chips) will be burned, generating about 58 kilotons of wood fly ash (WFA) (CSP 2015).

Previous studies have confirmed that most of bio-fuel fly ash (also WFA) are suitable for various construction sub-sectors, including road-construction. Most of the bio-fuel fly ash could be recycled in the ground construction. The rest could be used in any other way, for example, as soil fertilizer etc. A very small portion of the ashes in such a case would be required to deposit in landfills, if the quality would not be sufficient, or because of geographical location, it would not be profitable. There are significant differences in quality among various bio-fuel fly ashes from different combustion plants (Mácsik *et al.* 2012), however, test data obtained testing WFA from LLC “FORTUM Latvia” (LCC FL) (Bubbling fluidized bed furnace (BFB furnace)) show relatively small deviations in chemical and physical-chemical properties.

Bio-fuel fly ashes has been successfully used in road construction in many pilot-projects in Europe (Bohrn, Stampfer 2014; Bjurström, Herbert 2009; Mácsik *et al.* 2004, 2009; Mácsik, Svedberg 2006; Lahtinen *et al.* 2005a, 2005b; Supancic, Odenberger 2012; Svedberg *et al.* 2008; Vanhanen *et al.* 2014; Vestin *et al.* 2012). Stabilized roads shows enhanced durability and bearing capacity relative to the conventionally designed

road sections in the same circumstances. Frost susceptibility, heave, deformation and cracking problems are reduced.

In general, physical and chemical properties of WFA varies depending on the burned material – tree species, parts of tree, size and age of tree, and also combustion techniques (Pitman 2006). Mineralogical analysis shows that the wood fly ash contains alkali elements (pH = 12–13), especially oxides, hydroxides or carbonates. WFA contains chemical elements, such as K, Ca, P, Fe, Al and heavy metals, such as Mn, Cu, Zn, As, Cd, Hg, Cr, Pb and others almost in the same proportions as burned material.

According to the European Parliament and Commission Decision 2014/955/EU bio-fuel fly ash is not hazardous waste. If bio-fuel ashes have not the waste status, they are subject to the European chemicals regulation – REACH (Regulation (EC) No 1907/2006). Chemical manufacturers or importers inside the European Economic Area (EEA), producing or importing more than one ton of chemicals per year, the registration must be submitted to the European Chemicals Agency (ECHA).

It was found that WFA from LCC FL chemical composition is characterized by high SiO₂ (>45.00%), Al₂O₃ + Fe₂O (R₂O – (>5%)) and CaO (>22%) content. Calculated hydraulic modulus (m = 2.0–2.8), distinguishing WFA as an active pozzolan or highly hydraulic material.

Materials and methods

This study presents soil stabilization with wood fly ash (WFA) from LLC FL at laboratory.

Wood fly ash (WFA) properties

WFA from LCC FL combustion plant is generated in BFB furnace. The WFA chemical composition, calculated hydraulic modulus and loss of ignition (LoI) is given in Table 1.

Table 1. WFA from LCC FL chemical composition

Component	Content, %	Accuracy, ±%
SiO ₂	43.1–47.6	±0.7
SiO ₂ active	3.5–5.0	±0.7
R ₂ O ₃ (Al ₂ O ₃ +Fe ₂ O ₃)	5.6–9.0	±0.7
CaO	22.7–24.7	±0.5
MgO	1.6–3.2	±0.3
Fe ₂ O ₃	1.1–1.3	±0.1
K ₂ O	4.3–4.9	±0.3
Na ₂ O	0.6–1.2	±0.1
Al ₂ O ₃ =R ₂ O ₃ Fe ₂ O ₃	4.4–7.9	±0.5
SO ₃	5.0–8.3	±0.5
Hydraulic modulus	2–2.8	–
LoI (1000°C)	4.5–5.1	–

Particle size distribution analysis (sieving method) has identified that 15.57–18.10% of WFA particles are larger than 250 µm, 45.93–56.52% retains in between 65 µm and 250 µm sieve, but 25.40–34.30% of particles are smaller than 65 µm.

Specific surface of WFA was determined with nitrogen multi-layer absorption BET method (NOVA 1200e apparatus). It was found that specific surface for the WFA form LLC FL is 2.456–3.792 m²/g.

Soil and WFA preparation prior mixing

Prior the soil – binder mixing, the soil was sifted through 5mm sieve and WFA was sifted through 2 mm sieve and dried in oven at 105±5 °C for at least 24 hours.

Soil was taken from quarry, which is normally used for road construction purposes. Sandy (Sa) soil was further studied. The optimal water content for Sa and Sa mixtures with 10% and 20% WFA was determined according to Proctor test LVS EN 13286-2:2012.

The WFA attracts water available for the pozzolanic reactions and, because of heat generation in those reaction, some water might further evaporate. Therefore, it is difficult to determine the optimum water content and maximum dry density for soil – WFA mixtures.

WFA pozzolanic activity was determined based on CaO content reduction in time (Massazza, Costa 1976). Reviewing this phenomena after 1, 3, 7, 24 hours and 3, 7, 14 days, it was found that already after 24 hours there is no significant CaO changes in test specimens. This means that pozzolanic reactions for used WFA enhances for the first 24 hours. Assuming that water and CaO molecular weight ratio is 3.11 (56/18), the consumed water will be 1/3 of available CaO for reaction.

It was found that CaO available is approximately 5%, although the total CaO content in WFA was determined to be 22.7–24.7% (see Table 1).

The optimal water content for Sa was determined 7.0% with maximal dry density 1793 kg/m³ respectively.

Soil and WFA mixing and curing

Natural sand (Sa), Sa mixtures with 10% and 20% WFA were compacted at optimal water content according to Standard Proctor test LVS EN 13286-2:2012, and California bearing ratio (CBR) tested according to LVS EN 13286-47:2012 for cured samples after 96 hours immersed in water with 2 kg surcharge and after 7 days sealed simultaneously. At the same time also Immediate bearing index was determined for natural soil and mixture with 10% WFA.

Sample conditioning for 96 hours immersed in water with 2 kg surcharge was chosen to simulate upper road surface structural load and saturated state during long consecutive rain or snow melting (thawing) period in spring. 96 hours (4 days) in water and 7 days without change in water content sealed were chosen in accordance to LVS EN 14227-15:2016 Annex A.

Results

According to LVS EN 14227-15:2016 there are requirements of the fresh soil – binder mixture and laboratory mechanical performance classification by California bearing ratio (CBR).

In order to evaluate the fresh mixture performance of WFA stabilized soil, Immediate bearing index was determined. Mixture was stored in bags in a sealed condition for 30 min to 60 min maximum in accordance to LVS EN 13286-47:2012. The immediate bearing index determined for natural Sa and Sa – WFA (10%) mixture is given in Figure 1.

Fig. 1. Immediate bearing index (CBR value, %) for natural soil (Sa) and WFA (10%) stabilized Sa

It can be seen (see Fig. 1) that by adding 10% of WFA to the sand (Sa) CBR value rises from 8.15% for natural soil to 37.75% for WFA (10%) stabilized in average. Because immediate bearing index (IBI) for stabilized soil is greater than 30%, it can be considered as IBI₃₀ category according to the Table 4 in LVS EN 14227-10:2006A. This is important if there are defined IBI category requirements to reach for the particular design.

Obtained immediate bearing index results for fresh soil – WFA showed that WFA can be sufficiently good

binder for sand, and further strength development was studied curing compacted sample sealed 7 days and 4 days fully soaked with 2 kg surcharge. CBR test results for natural soil (Sa) and Sa – WFA mixtures with 10% and 20% conditioned in those regimes are given in Figures 2 and 3.

Fig. 2. CBR value (%) for natural soil (Sa), WFA (10%) stabilized Sa and WFA (20%) stabilized Sa conditioned 7 days sealed

Fig. 3. CBR value (%) for natural soil (Sa), WFA (10%) stabilized Sa and WFA (20%) stabilized conditioned immersed in water for 4 days

It can be seen that CBR value reaches 34.1% and 43.4% for Sa + WFA (10%) and 48.65% and 46.0% for Sa + WFA (20%) conditioning 4 days immersed and 7 days sealed respectively (see Figs 2 and 3). Based on mechanical performance both sand (Sa) WFA (10% and 20%) mixtures can be classified as CBR₄₀ class according to Table 6 in LVS EN 14227-15:2016.

Water resistance (strength for samples immersed in water/strength for samples sealed) for soil – 10% WFA mixtures is close to 0.8, but for soil – 20% WFA mixture even >1. WFA stabilized Sa water resistance is classified as sufficient (water might be even favourable for strength gain). Swelling after full soaking with water also were observed measuring linear swelling with indicator on top of the sample. There was not found any remarkable

(>1 mm) swelling potential for natural and WFA stabilized soil.

Conclusions

Because of possible deviations in chemical and physical-chemical properties for different WFA, it is of particular significance to investigate stabilization effects at laboratory. In order to evaluate the fresh mixture performance of WFA stabilized soil, Immediate bearing index was determined. Stabilized soil – WFA was classified based on these initial measurements:

1. It was found that sand (Sa) stabilized with 10% of WFA shows to 37.75% immediate bearing index, so grouping mixture IBI₃₀ category in accordance to LVS EN 14227-15:2016 (see Fig. 1).
2. Immediate bearing index enhanced more than 4 times comparing natural Sa and stabilized with 10% WFA, indicating that WFA is sufficiently good stabilizer and further strength measurements should be studied.

Natural sand (Sa), Sa with 10% and 20% WFA was conditioned 7 days sealed and 4 days immersed in water according to LVS EN 14227-15:2016 Annex A:

1. It was found that CBR value reaches 34.1% and 43.4% for Sa + WFA (10%); 48.65% and 46.0% for Sa + WFA (20%) conditioning 4 days immersed and 7 days sealed respectively (see Figs 2 and 3).
2. Based on mechanical performance sand (Sa) – WFA (10% and 20%) mixtures can be classified as CBR₄₀ class according to Table 6 in LVS EN 14227-15:2016.
3. Water resistance for all natural and stabilized soil samples were sufficient or even might be favourable for higher strength gain.
4. It was found that soil – 20% WFA mixture shows better results than 10% WFA mixture conditioning 7 days sealed and even more conditioning 4 days immersed in water.

Data obtained in this study verified that WFA from LLC FL BFBF combustion plant is good hydraulic binder with sand and could be used for different ground construction purposes. The one of most promising construction sub-sectors could be road construction, where great amount of road base material could be replaced and reduced if stabilized with WFA, thus reducing load on the landfills and dumped WFA amount. It would be necessary to continue to optimize different soil type – WFA mixtures, applying to the specific road construction purposes in road structural layers. One of the objectives would be to evaluate the freezing-thawing performance of WFA stabilized soil, since road base and subbase structures are exposed to the successive freezing and thawing.

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